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Polymers for Sewer Flow Control

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Polymers

for

Sewer Flow Control

The Development and Demonstration of the Use of
Polymers to Reduce or Eliminate Sewer Overflows by
Flow Energy Reduction

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
DEPARTMENT OF THE INTERIOR

by

The Western Company
2201 N. Waterview Parkway
Richardson, Texas 75080

Program No. 11020 DIG
Contract No. 14-12-34

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FWPCA Review Notice

This report has been reviewed by the Federal Water Pollution Control Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Pollution Control Administration.

ABSTRACT

Six water-soluble polymers were investigated to determine their effects upon aquatic flora and fauna, flow characteristics of wastewater, and the operation of a wastewater treatment plant.

It was found that the polymers and gels, in the magnitudes tested, were not toxic to bacteria, algae, or fish, and did not act as a nutrient for algae growth.

Based upon calculations obtained from flow test data, a maximum flow increase of 2.4 times the flow prior to injection could be obtained if a constant head was maintained. Laboratory flow test data indicated that if flow rates were held almost constant prior to and during polymer injection, a reduction in the static head occurred as a result of friction reduction within the fluid.

The most effective polymers in providing energy reduction were Polyox Coagulant-701, WSR-301, and AP-30; however, AP-30 required higher polymer concentrations to obtain equivalent flow characteristics.

In field tests on a 24-inch diameter line, it was found that polymer concentrations of between 35 and 100 mg/l, decreased frictional flow resistance sufficiently to eliminate surcharges of more than six feet.

Based upon an economic analysis, the average annual cost of new construction was approximately five times the cost of using polymers during peak storm-flow periods.

This report was submitted in fulfillment of Contract 14-12-34 between the Federal Water Pollution Control Administration and The Western Company.

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SECTION I

PROJECT CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From the literature study of potential water-soluble polymers, six candidates were selected for evaluation in the laboratory and six-inch sewer line test facility.

Trade Name	Supplier	Unit Cost# $ /lb.	Chemical Class
Polyox Coagulant-701	Union Carbide	1.45	Polyethylene Oxide
WSR-301	Union Carbide	0.80	Polyethylene Oxide
AP-30	Dow Chemical	2.15	Copolymer (Acrylate/ acrylamide)
D252	Calgon Corp.	1.25	Copolymer (Acrylate/ acrylamide)
FR-4	Hercules Corp.	1.60	Copolymer (Acrylate/ acrylamide)
J-2FP	The Western Company	0.40	Galactomannan

The unit costs are for less than 2,000 pound quantities, April, 1969. Variable unit cost reductions are available on larger quantities.

Although flow studies indicated that Polyox Coagulant-701 and WSR-301 provide maximum friction reduction when suspended in a gelled slurry and injected into water, each potential polymer candidate and slurry nonsolvent (isopropyl alcohol or cellosolve) was tested to determine what affect each had upon bacteria, fish, and algae. Tests conducted indicate that the polymers and nonsolvents are not detrimental to bacteria growth and, therefore, will not disrupt the biological treatment of sewage in wastewater treatment plants. Tests conducted on algae in a polymer environment indicated that the polymers have no toxic and only nominal nutrient affects. The fish bio-assay indicated that in a polymer slurry concentration of 500 mg/l, some fish deaths resulted; however, flow tests indicated that polymer slurry concentrations above 250 mg/l provide no additional flow benefits, and therefore, 500 mg/l polymer concentrations would not be required in actual pollution control applications. Thus, indications are that the use of the above polymers and polymer slurries as friction reducers in municipal sewers will not produce fish kills in the receiving lake or stream.

After determining that the selected polymers were not toxic to aquatic flora and fauna, each polymer was tested in the six-inch sewer line facility to determine flow characteristics while maintaining a constant flow rate. The polymers ranked in the order presented above with respect to derived percent flow increase at a constant pressure head (see Appendix

C for example of how flow increase was derived). The maximum derived flow increase was about 2.4 times the flow prior to injecting a polymer slurry. The following data indicate the calculated percent flow increase, based on data obtained at a constant flow rate of 300 gpm and a polymer concentration of 200 mg/l or ppm by weight.

		Derived (2)	
Polymer	Temperature °F	Flow Increase (%)	Ratio of Final-to-Initial Flow
P. C. -701 (1)	38	144	2.44
P. C. -701	73	136	2.36
P. C. -701	90	146	2.46
WSR-301	38	138	2.38
WSR-301	70	117	2.17
WSR-301	90	133	2.33
AP-30	38	114	2.14
AP-30	70	100	2.00
AP-30	90	104	2.04
D252	38	26	1.26
D252	70	22	1.22
D252	90	27	1.27
FR-4	38	24	1.24
FR-4	71	36	1.36
FR-4	90	24	1.24
J-2FP	72	12	1.12

(1) P.C. is abbreviation for Polyox Coagulant.

(2) Percent flow increase = $\frac{\text{Flow with Polymer - 300 gpm}}{\text{300 gpm}} \times 100.$

The two polyethylene oxides, WSR-301 and Polyox Coagulant-701 were most effective in reducing friction losses; however, small-scale laboratory work indicated that both polymers' friction-reduction abilities were reduced in a sewage media when compared with water. Therefore, tests using various sewage concentrations and temperature variations were conducted in the six-inch test facility. Typical results of these tests, conducted at a constant flow rate of 300 gpm and a polymer concentration of 200 mg/l or ppm by weight, are presented below:

Polymer	Sewage Concentration ml/l of Settleable Solids	Sewage Temperature ^0F	Derived Flow Increase (%)	Ratio of Final-to-Initial Flow
WSR-301	3	38	105	2.05
WSR-301	3	70	97	1.97
WSR-301	3	90	94	1.94
WSR-301	9	38	125	2.25
WSR-301	9	70	135	2.35
WSR-301	9	90	109	2.09
P. C. -701	3	38	103	2.03
P. C. -701	3	73	110	2.10
P. C. -701	3	90	117	2.17
P. C. -701	9	38	127	2.27
P. C. -701	9	73	142	2.42
P. C. -701	9	90	117	2.17

These results show that the temperature and sewage concentration (settleable solids) should be considered prior to selecting a polymer additive. Additional tests on these two polymers at higher sewage concentrations also verify this requirement, as indicated by the following data:

Polymer	Sewage Concentration ml/l of Settleable Solids	Sewage Temperature ^0F	Derived Flow Increase (%)	Ratio of Final-to-Initial Flow
WSR-301	46	70	140	2.40
WSR-301	68	70	88	1.88
WSR-301	100	70	79	1.79
WSR-301	115	70	56	1.56
P. C. -701	44	70	126	2.26
P. C. -701	85	70	109	2.09

In particular, consideration should be given to the polymer AP-30 when the above factors (temperature and settleable solids) are in the range of 70 ml/l and 70°F. The AP-30 polymer was found to be relatively stable over the temperature range of 38°F to 90°F, and relatively unaffected by sewage concentration; however, the cost and higher polymer concentration (250 mg/l as compared with 200 mg/l of WSR-301 and 100 mg/l of Polyox Coagulant-701 to achieve similar flow characteristics) required by AP-30 should be considered in its use. Also, polymer FR-4 was not affected by sewage, but was not as effective in providing friction reduction as polymers shown in the above data.

Polymer D252 was less effective than Polyox Coagulant-701, WSR-301 and AP-30 in reducing frictional flow losses; however, because of the tendency of this polymer to form a cohesive mass when dispersed in water (although suspended in a nonsolvent gel), it was replaced in performance order by FR-4, which has very similar flow characteristics.

Polymer J-2FP required from two to five times the concentration required for the other polymers tested. Although this polymer costs less, the cost difference was not sufficient to overcome its inefficiency.

Limited tests were conducted in which Polyox Coagulant-701, WSR-301, AP-30, and FR-4 were used to determine what effect a polymer slurry injection point location had relative to relieving a flow constriction. Test results indicated that the polymer slurry should be injected upstream and near the pipe constriction.

Sludge drying tests were also conducted on the selected polymers to determine if the polymers affected drying rate (see Table IX and Figure 16). It was found that during the first four to six days of drying, the moisture content of the sludge and polymer mixtures exceeded that of sludge alone; however, the moisture content at the end of 28 days was about 10 percent less in the mixture of sludge and polymer, indicating that, by using polymers, the time sludge must remain on drying beds prior to removal and disposal can be reduced.

The biochemical oxygen demand (BOD) of polymers has no significant affect upon the BOD of sewage; however, an increase in chemical oxygen demand (COD) was measured as polymer concentration increased, as shown in Table XVI.

The two most effective friction reducers, the polyethylene oxides, were water soluble and required thorough dispersion of the individual polymer particles during initial contact with water. The most effective technique for obtaining this dispersion was the predispersion or suspension of polymers in a gelled nonsolvent. The nonsolvents tested for toxicity were cellosolve and isopropyl alcohol. Data indicated that, for the concentrations tested (maximum concentration was 500 mg/l), significant toxicity effects were not observed. Both nonsolvents were used in the test phases and no advantage of either over the other was apparent; however, cellosolve's cost is slightly higher, $1.12 per gallon as compared with $0.69 per gallon for isopropyl alcohol.

The nonsolvent was gelled by adding klucel H (supplied by the Hercules Corp. at $1.30 per pound for small quantities), which is a water-soluble cellulose ether powder. The technique used in obtaining a gel is described in Appendix D.

After the gel was formed, the polymer was added slowly, about 120 pounds of polymer each 20 minutes, while the gel was circulated through the specially designed batch tank, resulting in a suspended polymer slurry.

The weight proportions generally used in making the slurry were 69.25 percent nonsolvent, 0.75 percent gelling agent, and 30.00 percent polymer. Slurries were also made by using 40 percent polymer; however, this percentage was the maximum polymer content that would remain in suspension. Also, the gelling agent was reduced to 0.5 percent for a 40 percent polymer concentration.

To obtain dispersion in water, the slurry was injected (metered by a valve and flow meter) into the sewage by an eductor which provided extreme turbulence and mixing. This method was found to be efficient, and the equipment required was inexpensive. To operate the eductor, sewage was pumped from the sewer line through the eductor and the sewage and slurry were then returned to the line.

Tests were conducted by using the two most efficient polymers to observe their effects upon a 24-inch sewer line which was frequently surcharged as much as six feet. Test results showed that a decrease in energy or static head on the line occurred after polymer was injected into the line, although the volume of flow carried by the pipe increased or varied only slightly.

It should be noted that the primary purpose of the test was not to determine the percent flow increase that could be obtained, but to determine if each polymer provided sufficient friction reduction to eliminate surcharged conditions. Both of the polymers tested eliminated surcharges; however, lower polymer concentrations required longer time periods to obtain the same head reduction that was obtained at the higher polymer concentrations.

The time required to obtain head reduction is also dependent upon the length of line and upstream conditions (amount of sewage accumulated within system which, in effect, serves as a reservoir). It is apparent, therefore, that potential trouble areas within a system should be monitored and polymer injected at low concentrations to maintain the flow within the pipe rather than delay injection until overflow conditions are evident. Such a monitoring system could be made to operate automatically by a level detection system which actuates pump motors and valves of the injection equipment.

Limited test data obtained from investigations conducted on a wastewater treatment plant indicated no definite improvements in the filtration and sedimentation rates. Also, no adverse effects upon the treatment process were observed.

Recommendations

It is recommended that the project's results and the potential polymer uses for eliminating surcharged flow conditions be made available to the city public works officials, city engineers, consulting engineers, plant engineers of industry, and various health officials, so that additional applications for polymer use will be investigated and additional full-scale tests conducted to supplement the known data.

To avoid the expense of using a slurry to obtain hydration of the polymer particles, investigations should be conducted into methods of modifying polymers to permit dry feeding directly into the wastewater.

Additional studies should be conducted to determine the degradation effects of mechanical agitation, such as occur in pumps, upon polymer chains (see Appendix B). Also, the degradation effects of polymers flowing through pipelines over long distances should be investigated. Polymer chain scission will result in a reduction in the aqueous solution's viscosity and affect its friction-reduction capability.

The efficiency of various polymer concentrations in large-diameter (30 inches and greater) pipes is not known, as explained in Appendix B. Projects using polymers in such pipes should be conducted to determine characteristics of flow and efficiency.

The applicability of polymers to force mains from sewage lift stations should be investigated. Results reported on this program indicated that polymers could increase the capacity of pumping units by reducing the total system head as a result of friction loss reductions. Also, by maintaining the same total dynamic head on a system, line capacities could be increased to prevent sewage bypasses during peak flow periods.

The effect of polymers on flow conditions in various conduit cross-section configurations should be studied.

Studies -- including full-scale sludge drying studies -- should be conducted to determine what influence friction-reducing polymers have on filter-rock biota and the activated sludge treatment process.

The effects of various industrial wastes upon the friction reduction capabilities of polymers should be determined.

An actual flow-test program should be conducted over a period of several months to determine the effectiveness of this technique to prevent pollution of natural water systems, and to obtain actual operational expense of the technique.

Additional mechanical equipment should be investigated to accomplish both slurry injection and dry feeding of polymer.

Finally, periodic investigations should be conducted to evaluate new potential friction reducing materials and existing polymer improvements.

SECTION II

INTRODUCTION

Purpose of Project

Since 1956, when Congress enacted the Federal Water Pollution Control Act, (amended in 1961, 1965, and 1966), an increased effort has been made nationally to eliminate water pollution and restore our natural water systems to a desired quality standard. To achieve this goal, improved and more effective methods of treating industrial and domestic wastewater are being investigated and developed; however, the development, construction, and effective operation of better treating facilities cannot prevent the continued pollution of our waters from overflows of wastewater resulting from surcharged flow conditions in sewage collection systems.

A potential method for controlling this source of pollution is the technique of using high molecular weight polymers to reduce frictional resistance to flow. This reduction lowers the energy (static head, in a gravity flow system) required to drive the wastewater. So, by maintaining a constant energy level (or head), increased flow capacity can be obtained with the use of such polymers in existing sewer pipe.

This technique is applicable to both combined and separate sewer lines during both wet- and dry-weather surcharges.

An understanding of the extent and magnitude of urban wastewater overflows and surcharges has been amplified by recent studies. Combined sewers are used by 29 percent of the sewered population of the United States--eight states apparently have no combined sewers in use at this time (Reference 1). The feasibility of separating combined sewers is complicated by cost (estimated on a national basis, per capita cost is $835) and by the areas served, i.e., those areas with greatest population densities and commercial activities (Reference 1).

In those areas in which combined sewers do not present problems, overflows resulting from ground-water infiltration and dry-weather overflows (caused by insufficient line capacity) produce hazards to public health.

The solution to the above pollution problems has been approached by investigating new or improved techniques and ideas of flow containment (control, treatment, and combinations of control and treatment).

This report describes and presents the results of a Federal Water Pollution Control Administration sponsored research project which investigated and demonstrated one method of containing and controlling flow within sewer collection systems--the use of fluid flow friction-reducing polymers. Other methods of flow control and containment currently being investigated by others include a pressure sewer line within an existing combined sewer, a system to divert stormflow to an external storage system and later return to the system, means of modifying plumbing fixtures and system design, means of reducing ground-water infiltration, systems of internal storage and later discharge, and ways to control land use.

Scope of Project

In the development and demonstration of the use of water-soluble polymers for reducing frictional losses within sewer pipes, potential adverse or toxic affects of both polymers and polymer nonsolvents on the aquatic flora and fauna of streams and treatment plants were investigated. The selection of polymers to be investigated was based upon a study of 1) the literature describing their characteristics and properties, 2) The Western Company's experience in effective use of polymers, 3) the investigations and research reported by others and 4) small-scale laboratory flow tests. Based on the study of available polymers and preliminary flow tests and using specific criteria for selection, six polymers were used to determine the extent of flow increase each caused in a sewage conveyance system, and if each was compatible with the sewer environment.

While determining that the selected polymers and nonsolvents were compatible with a stream and sewage environment, extensive flow tests were conducted on a specially designed six-inch sewer line test facility. These tests were conducted by using various polymers and polymer concentrations in both water and sewage to determine the effects of sewage concentrations, as measured by settleable solids, upon the effectiveness of the polymer and polymer concentration to reduce frictional resistence to flow.

Flow tests were also conducted to determine the optimum location relative to a surcharge for injecting polymer to eliminate various flow constrictions. Also, flow tests were conducted in a large-size sewer to determine actual installation results and information relative to the flow of wastewater in sewers containing polymers.

As part of this installation test, equipment was designed and fabricated to disperse the polymers into sewage.

Finally, a cost-benefit analysis was made to provide an economic measure of the value of using friction-reducing polymers in a sewer system.

The program scope also included tests on a wastewater treatment plant to determine what affect the polymers would have on 1) the settling of solids, 2) the trickling filter and 3) sludge drying rates. These tests were conducted in a plant which contained a clarigester (mechanized clarifier superimposed over a mechanized digester with a concrete tray between the two compartments--a variation of the Imhoff tank), a high-rate trickling filter, a sludge drying bed, and an oxidation lagoon (which served as a final clarifier).

Project Objectives

The primary objectives of this project were the selection of nontoxic, water-soluble polymers that produce reductions in frictional losses in wastewater, the development of an injection device and method of polymer injection, the demonstration of the economic feasibility of polymer use, and the determination of what affects the polymer and polymer slurries have on the operating characteristics of a wastewater treatment plant.

The secondary objective in selecting the best polymer for reducing friction losses in wastewater was to screen potential polymer candidates, based upon friction-reduction capability, sludge-drying characteristics, and toxicity to aquatic life, such as bacteria, algae, and fish.

The secondary objective in developing an injection device was to minimize equipment cost, size (for mobility) and operation and maintenance complexity.

The secondary objective in demonstrating the feasibility of injecting polymers was to reduce the static head on a surcharged line while minimizing the time required for head reduction to occur and the polymer concentration required to obtain the desired flow condition.

The secondary objective of the wastewater treatment plant test was to determine the affect polymers would have on detention time and removal of settleable solids, as well as the affect the polymers have on the trickling filter operation and on sludge characteristics.

SECTION III

LABORATORY EVALUATION OF POLYMERS

Literature Survey

As the first step in the program to determine the best polymer additives to use, a literature survey was conducted for the purpose of finding determinative information that could be used in the selection process of potential water-soluble polymers capable of providing friction reduction properties to sewage flow in a closed conduit. The following criteria were used for selecting water-soluble polymers for evaluation.

Friction-reduction capability.
Solubility in water.
High molecular weight.
Hydration (solubility) rate.
Shear stability in flow systems.
Storage life.
Toxicity to biological systems.
Flocculating and settling characteristics.
Availability from commercial sources.
Cost.

Further screening was then accomplished by evaluating the applicability of the additives to this particular program, based upon the contractor's experience, the experience of manufacturers of polymers, and consultation with the staff of the Federal Water Pollution Control Administration.

The principal sources of information used for the investigation were Chemical Abstracts, bulletins from commercial suppliers, and reports written by The Western Company and others (Appendix A).

Additives selected for further investigation as possible friction reducers (as a result of the literature survey) are listed in Table I.

Application of the screening criteria to the above additives resulted in the following six being selected for evaluation in the laboratory and in the six-inch model test facility: 1) Polyox Coagulant-701, 2) WSR-301, 3) AP-30, 4) FR-4, 5) D252, and 6) J-2FP. Each of these additives appeared to have specific advantages that resulted in its selection.

1) Polyox Coagulant-701 has a very high molecular weight (approximately 7×10^{6}) and produces a highly viscoelastic solution in water when added in relatively small quantities. This polymer is basically a flocculent which aids in the sedimentation process when and if it reaches a treatment plant. Also, it is generally lower in price than many other polymers investigated.

2) WSR-301 has essentially the same advantages as Polyox Coagulant-701, except that its molecular weight is approximately half that of 701. It, too, is low in cost when compared with other polymers considered.

TABLE I

PRELIMINARY SELECTION OF POLYMERS

Trade Name	Supplier	Chemical
1-DSM-50C	Union Carbide	Polyethylene oxide
WSR-301	Union Carbide	Polyethylene oxide
Polyox Coagulant 701	Union Carbide	Polyethylene oxide
Polyox F.R.A.	Union Carbide	Polyethylene oxide
K-PAM	American Cyanamid	Polyacrylamide
Superfloc 16	American Cyanamid	Polyacrylamide
D-252	Calgon Corporation	Copolymer (acrylate/ acryamide)
AP-30	Dow Chemical	Copolymer (acrylate/ acryamide)
J-2FP	The Western Company	Galactomannan
CMC-7H	Hercules Corporation	Copolymer cellulose
FR-4	Hercules Corporation	Copolymer (acrylate/ acryamide)
CMHEC-37M	Hercules Corporation	Carboxymethylhydroxyethyl cellulose
Gafloc C-61	General Aniline	-------------------
Gentrez AN-169	General Aniline	Copolymer (methylvinyl ether/maleic anhydride)

3) AP-30, based upon experience and data, had shown to be an excellent-flow-increasing additive.

4) FR-4, again based upon experience, was known to behave essentially the same as AP-30 in flow systems.

5) D252, characteristically like FR-4 and AP-30, was selected because, in powder form, it is manufactured in disc-like shapes, which greatly inceases its solubility rate in water.

6) J-2FP is low cost, has shear stability and, unlike the other five synthetic polymer additives, it is a natural polymeric material.

Laboratory Model Tests

After the best potential polymers were selected, each was flow tested to determine its capabilities. Tests were conducted in a 0.18-inch internal diameter tube to determine flow behavior of sewage/polymer solutions and sewage only. The small-scale tests were inexpensive and less time consuming than large-scale tests. Results of these small-scale tests provided the basis for the six-inch test line program.

An existing small-scale flow test rig, available in The Western Company's flow test laboratory, was utilized. This flow equipment (Figure 1) consisted of an air reservoir, a nine-gallon liquid reservoir, a temperature indicator, a five-foot test section of 0.18-inch internal diameter tubing, a differential pressure gage and a flow measuring device. With such a test rig, the shear on the polymer is minimized because it was energized with air rather than by mechanical means (thereby creating essentially the same condition that exists in a gravity sewer line) once the sewage/polymer solution is injected into the sewage flow. This test rig has been used for polymer evaluation on several in-house programs and on prior research contracts with the Naval Ordnance Test Station (Pasadena) and the David Taylor Model Basin. The credibility of the test device was established under these programs, which therefore, instilled a high degree of confidence in the data obtained for this program.

Tap-water friction tests were performed by using the facility to establish base data. A sewage containing nine-milliliter per liter settleable solids content was then made up in sufficient quantity so that sewage data could be determined for comparison with water data. The sewage was "manufactured" by diluting raw sludge with tap water in 35-gallon drums to give the desired settleable solids content.

The behavior of each selected polymer, at different concentrations, in tap water was determined to establish additional base data. Each water-polymer solution was allowed to hydrate approximately four hours before testing in the 0.18-inch rig. Polymer concentrations tested are shown in Table II.

TABLE II

WATER/POLYMER CONCENTRATION
USED IN 0.18-INCH DIAMETER TEST LINE

Polymer	Concentration (ppm)	Polymer	Concentration (ppm)
AP-30	10 & 100	J-2FP	50, 250 & 1250
FR-4	10 & 100	WSR-301	10 & 100
D252	10 & 100	Polyox Coagulant 701	10 & 100

The above test procedure was then repeated by using a sewage concentration of nine-milliliter per liter settleable solids (instead of tap water) and the polymer concentrations shown in Table II. This data was then compared with the water/additive data.

The data obtained from the tests performed in the small-scale flow facility are shown in Figures 2 through 7. Test data shown for the tap water/additive and the sewage/additive regimes compare flow behavior in each system.

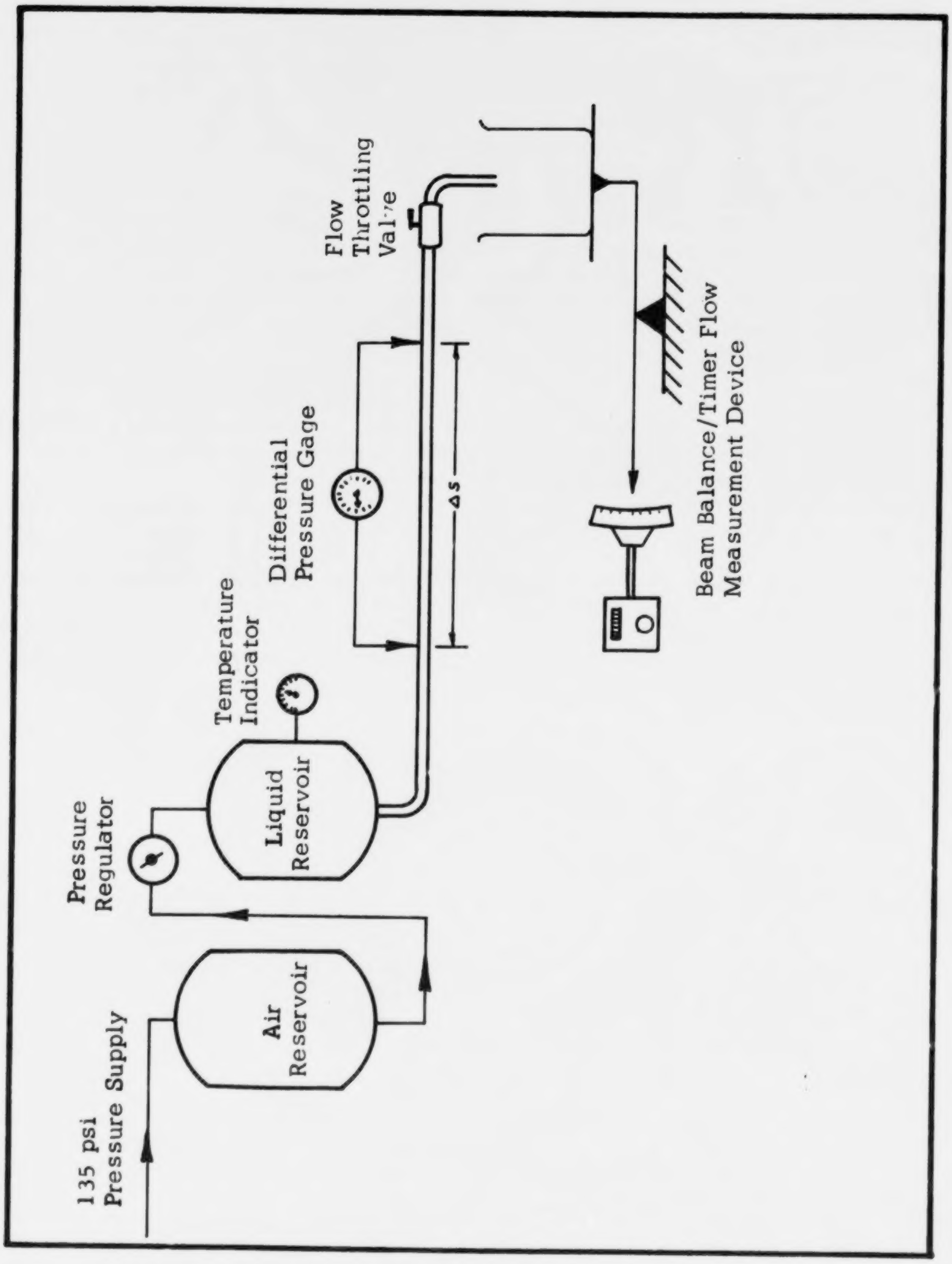

135 psi
Pressure Supply
Air
Reservoir
Pressure
Regulator
Liquid
Reservoir
Temperature
Indicator
Differential
Pressure Gage
Δs
Flow
Throttling
Valve
Beam Balance/Timer Flow
Measurement Device

Figure 1. Small Diameter Laboratory Flow Facility.

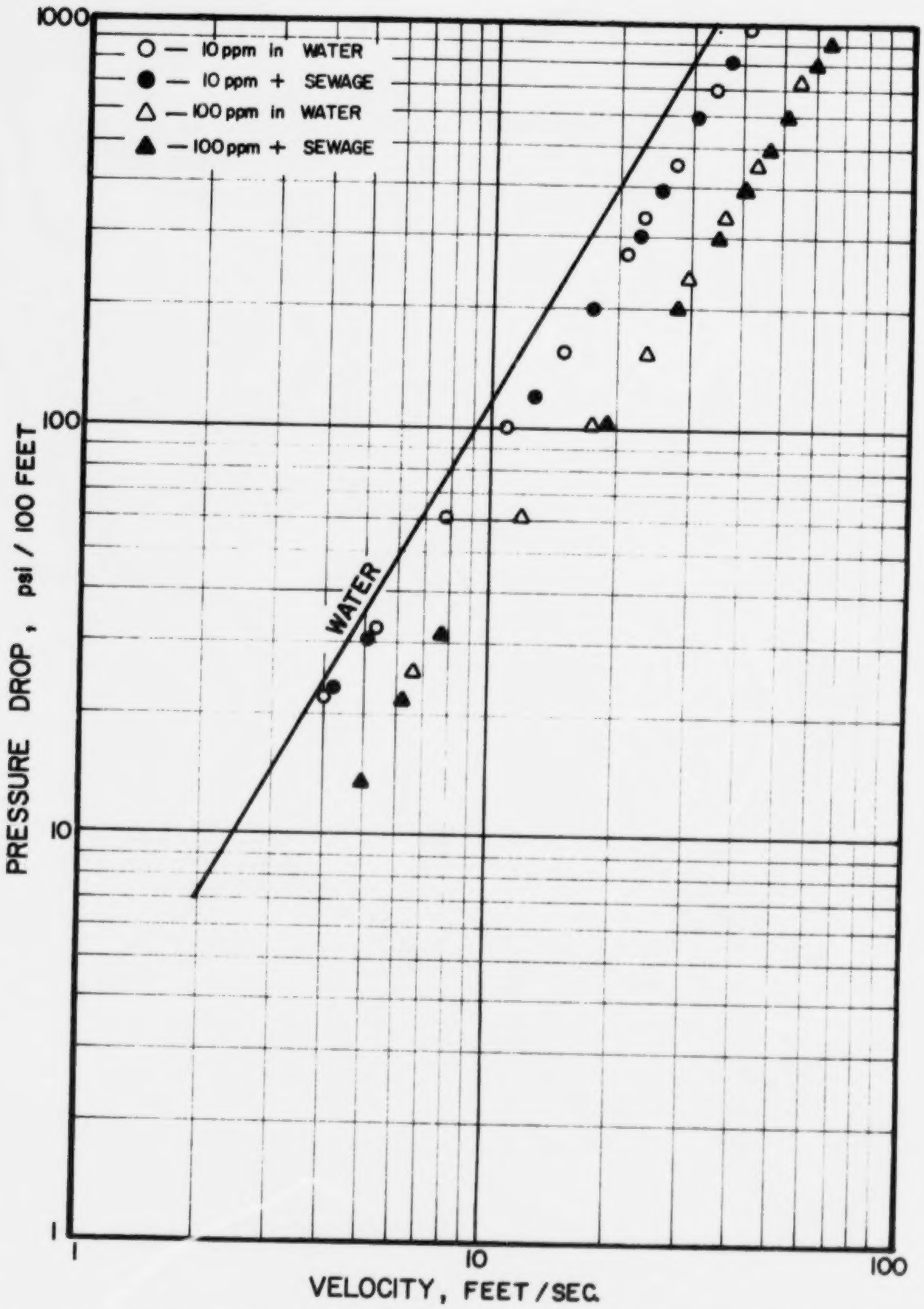


Figure 2. Comparison of AP-30 Friction Reduction for Water and Sewage (9 ml/l Settleable Solids) at 61°F in 0.18-Inch Test Facility.

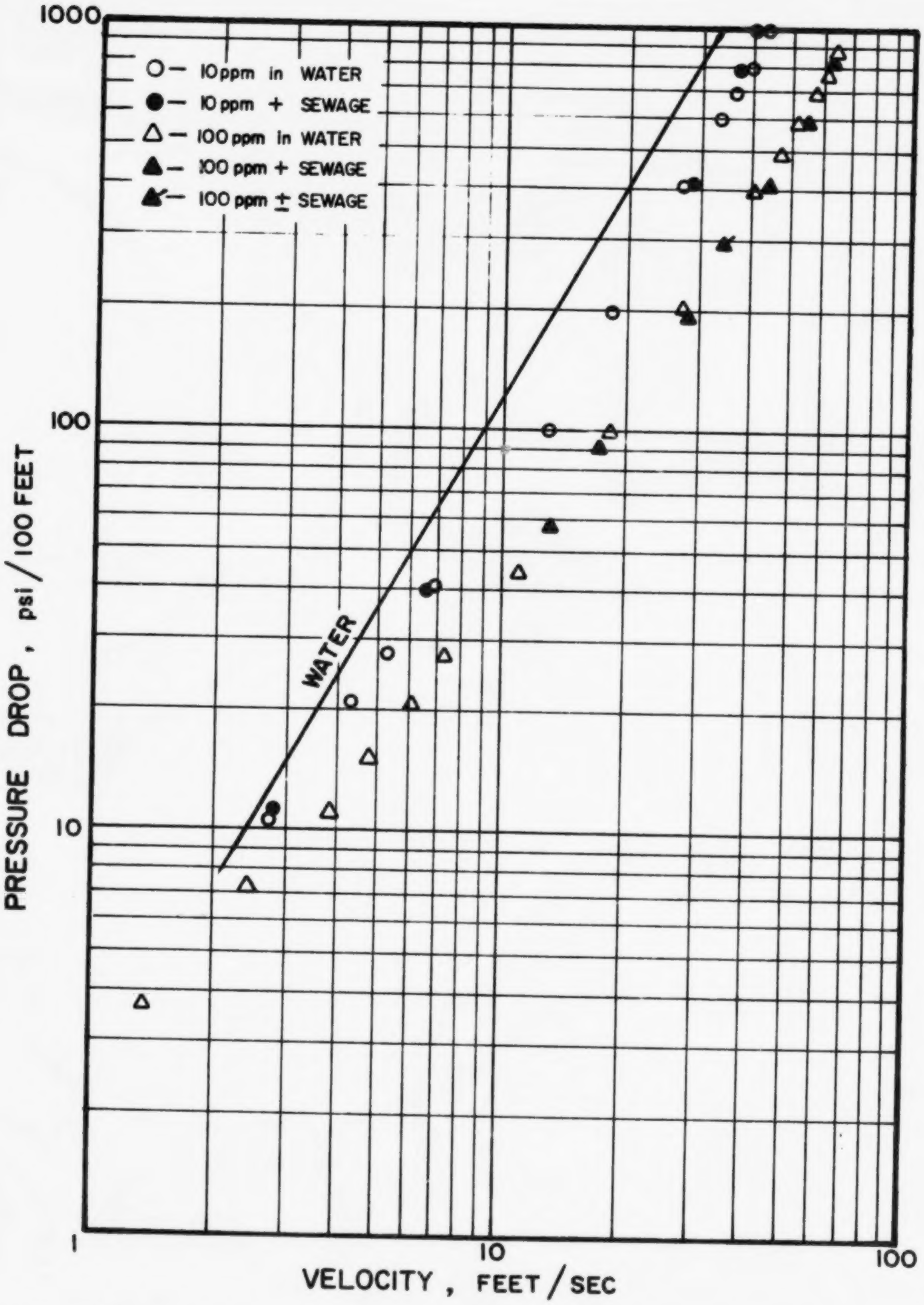


Figure 3. Comparison of D-252 Friction Reduction for Water and Sewage (9 ml/l Settleable Solids) at 61°F in 0.18-Inch Test Facility.

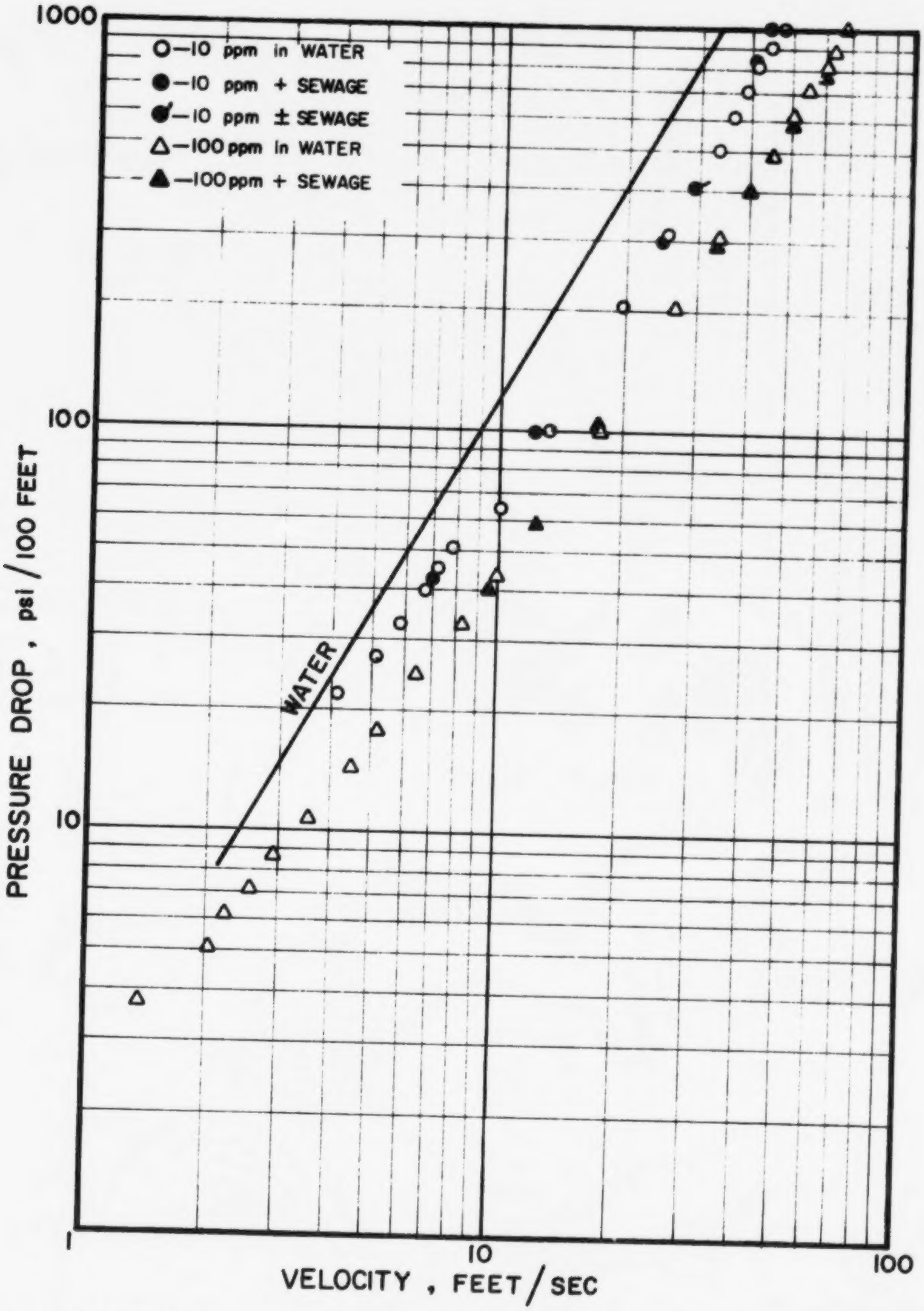


Figure 4. Comparison of FR-4 Friction Reduction for Water and Sewage (9 ml/l Settleable Solids) at 61°F in 0.18-Inch Test Facility.

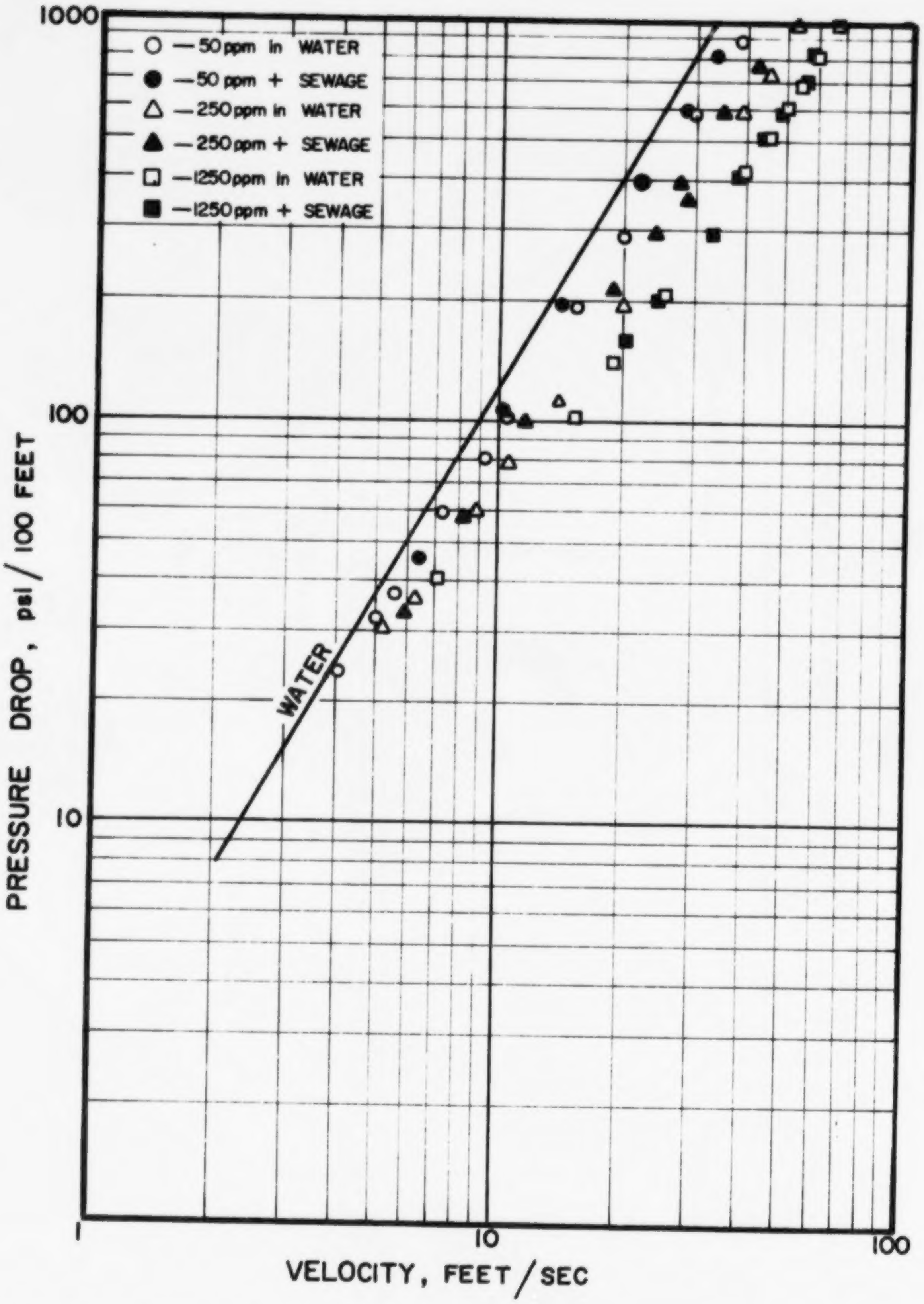


Figure 5. Comparison of J-2FP Friction Reduction for Water and Sewage (9 ml/l Settleable Solids) at 61°F in 0.18-Inch Test Facility.

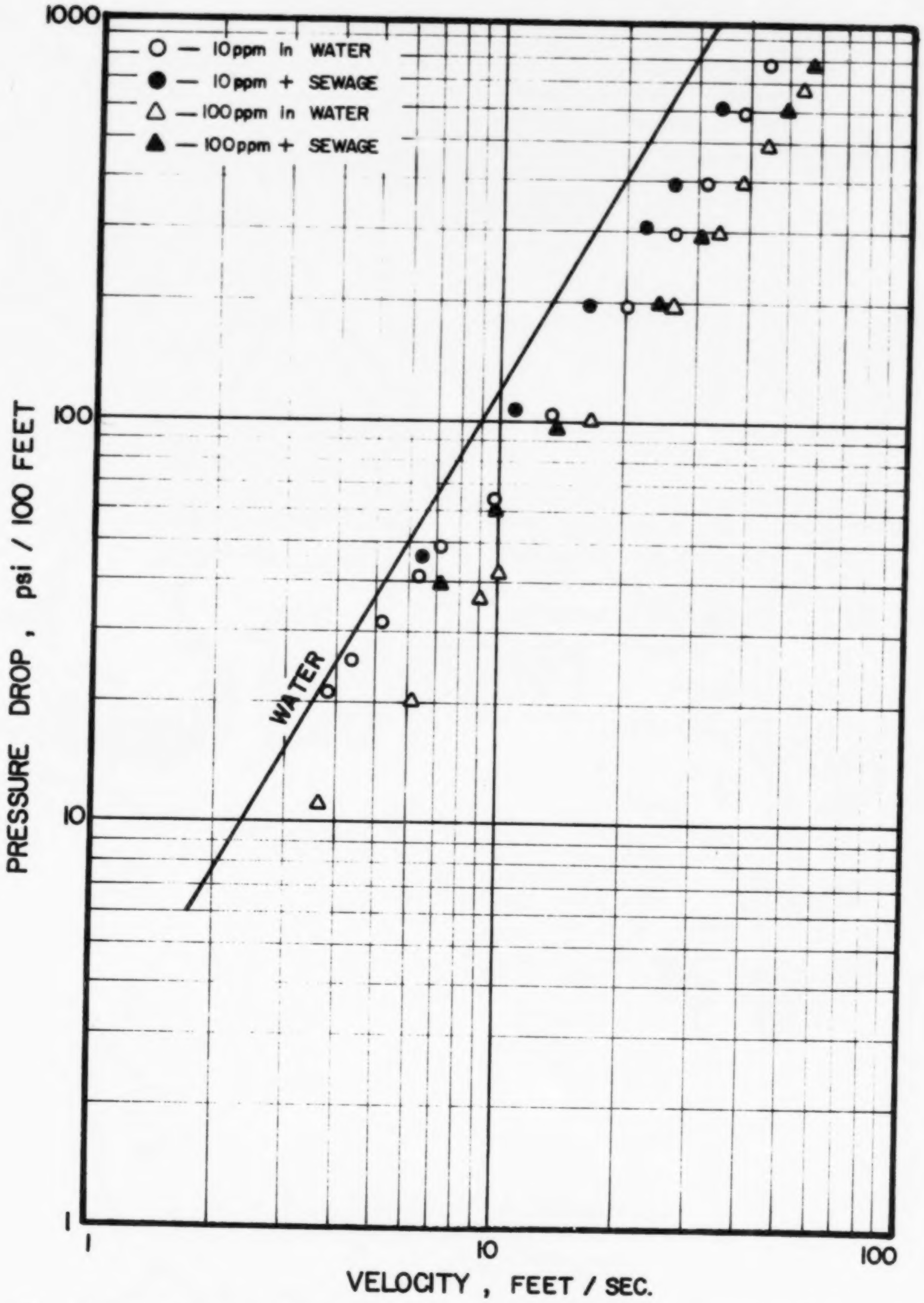


Figure 6. Comparison of WSR-301 Friction Reduction for Water and Sewage (9 ml/1 Settleable Solids) at 61^{0}F in 0.18-Inch Test Facility.

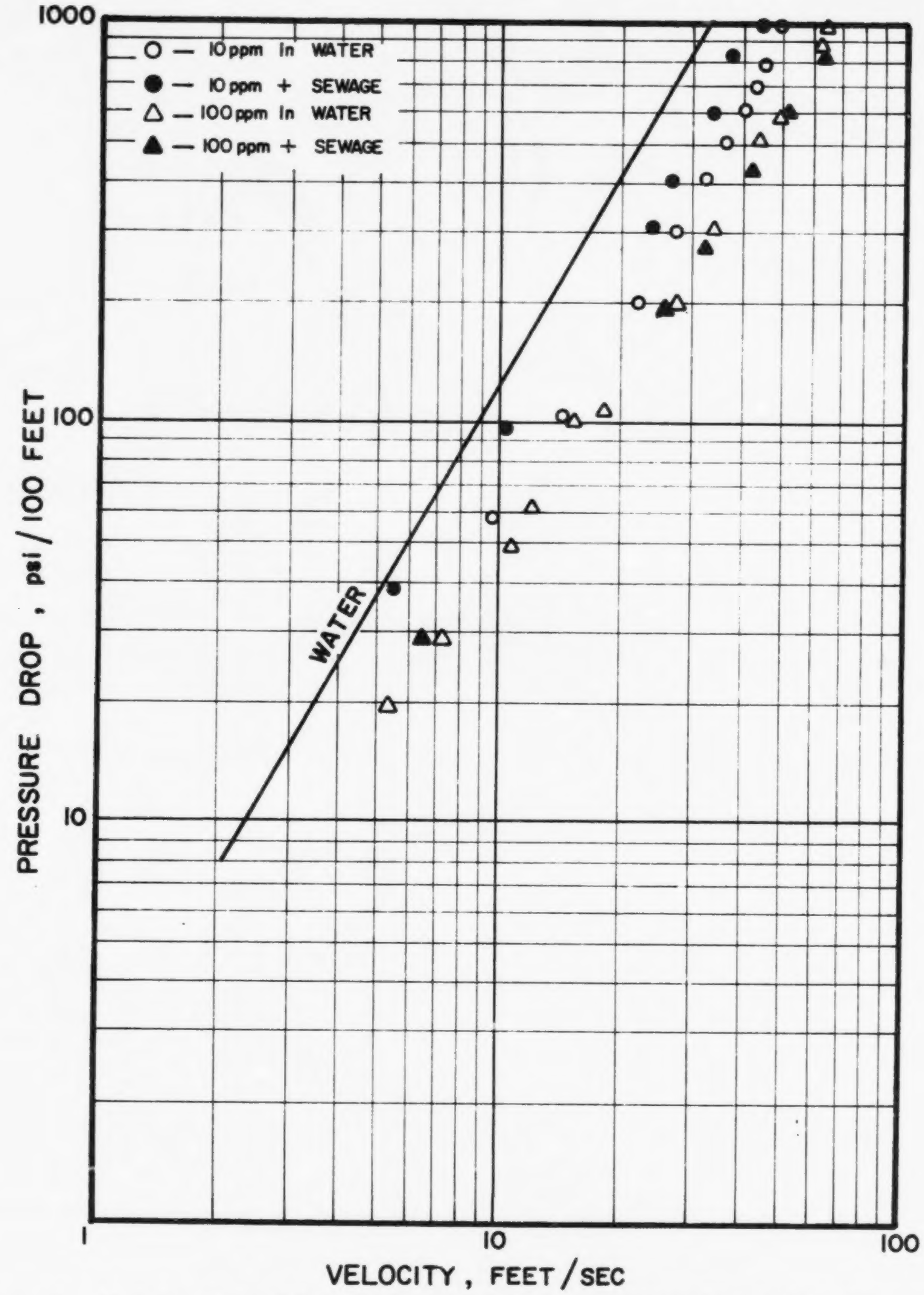


Figure 7. Comparison of Polyox Coagulant-701 Friction Reduction for Water and Sewage (9 ml/l Settleable Solids) at 61°F in 0.18-Inch Test Facility.

The sewage behaved rheologically (flow and viscosity), the same as water without additives. Consequently, a pressure drop per unit length $\left(\frac{\Delta P}{L}\right)$ versus velocity (V) plot of the data could be used to determine the affect of sewage on the additive as far as its friction-reduction ability was concerned.

A comparison of water/polymer with sewage/polymer data for AP-30, D252, and FR-4 (Figures 2, 3 and 4) showed no interference by the sewage on friction-reduction ability of the polymers. Since these three additives are acrylate/acrylamide type co-polymers, it would be expected that if one was not affected, the others would not be.

J-2FP, WSR-301 and Polyox Coagulant-701 showed a polymer/sewage interaction in the small-scale testing which was, to different degrees, slightly deleterious to their friction-reduction effect. Figures 5, 6 and 7 show the friction comparison of water/polymer with sewage/polymer data for J-2FP, WSR-301 and Polyox Coagulant 701, respectively; however, the deleterious effect of the sewage on friction reduction remains constant as the polymer concentration is increased; thus, it was concluded that a constant amount of the polymer was affected regardless of polymer concentration.

Biological Testing of Affects of Polymers on Aquatic Life

While flow tests were being conducted on the six selected polymers, toxicity and other affects upon bacteria, algae, and fish were determined by using standard methods (or accepted methods in specific instances).

Purpose of Tests. Since sewage is biologically decomposed in sewage treatment plants, it is desirable that the presence of polymers at varying concentrations not be detrimental to the bacteria in the collection and treatment systems. Therefore, toxicity tests (of polymers and polymer slurries toward sewer organism) were started early in the program.

Storm water from heavy rain results in surcharges and/or overflows in separate as well as combined sewers, as does infiltration, illegal connections, and insufficient line capacity. This wastewater is often completely or partially bypassed at the treatment plant and directly discharged into a lake or stream. The use of polymer injection to alleviate the surcharge condition in sewers must not extensively contribute to the pollution problems of these discharges, or cause fish kills, bacterial death or algae blooms. Therefore, polymers and polymer slurries affect upon algae and fish were also investigated.

Bacteria Test and Analysis Procedure. Random seed samples of raw sewage were taken from the Rowlett Creek sewage treatment plant, located in the City of Garland, Texas. A portion of the raw sewage was diluted 1:100 with distilled water. From this dilution, 1 milliliter was transferred to a sterilized petri dish containing 10 milliliters of nutrient agar. Three samples were prepared in this manner for a control group, then incubated at 37°C for 24 hours. After 24 hours, a bacterial plate count was made. Subsequent counts were made at selected time intervals to determine bacterial growth and death pattern in the sewage, which was controlled as described below for the polymer-sewage mixtures.

To evaluate the toxic effect of polymers on bacteria, two 200-milliliter Erlenmeyer flasks were filled with 100 milliliters of sewage, and a polymer added to achieve the desired polymer concentration. The polymer concentrations were evaluated at 100 and 500 milligrams per liter, which gave an upper and lower limit for evaluation. The tests were conducted at 2^{0}C and 29.5^{0}C in the constant-temperature bath. The Erlenmeyer flasks, containing polymer and sewage, were placed in the constant temperature bath and agitated at the rate of 85 strokes per minute to simulate movement in a sewer line. At fixed intervals after initial mixing, 1-milliliter samples were withdrawn from the flask and 1:100 dilutions were made with distilled water. Samples of 1-milliliter were withdrawn from the 1:100 dilution and transferred to the nutrient agar in the sterilized petri dish, then incubated. A bacterial count was conducted after 24 hours, repeating the procedure for the control group.

Figure 8 shows the theoretical bacterial growth and death cycle in a constant nutrient substrate. To properly evaluate the toxic effect of polymer for bacteria, an initial point was chosen on the growth and death curve (Figure 9a) to represent the initial raw sewage bacterial count which then became the 100 percent count of the micro-organisms. At each of the selected time periods, an increase or decrease in bacterial count was expressed as a percentage deviation from the initial count. A fixed nutrient condition was chosen as a control parameter, since changes in nutrient concentration (Figure 9b) affect the number of micro-organisms. With the initial nutrient fixed for the incubation period, any growth or death of bacteria is reasonably dependent upon the sewage and polymer or nonsolvent added.

Figure 9c indicates the theoretical relationship of time with bacterial count (i.e., that expected from the growth testing since the added polymer is a nutrient). The "sewage" curve indicates the growth of bacteria feeding on a sewage as the available nutrient and their subsequent decline as the nutrients are consumed. During the time period when the bacterial death occurs on the sewage curve, the bacterial count is increased slightly on the polymer and sewage curve and does not diminish as rapidly due to lack of nutrients.

The bacterial counts were made by using a Quebec Colony Counter on the petri dishes containing the sewage seeding or polymer and sewage seeding. Standard methods were used in counting. The tabulations of all data can be found in Table III.

Algae Test and Analysis Procedure. Water containing algae was obtained from the sludge bed drainage pond at the Duck Creek Sewage Treatment Plant (located near Garland, Texas). Three 200-milliliter, sterilized Erlenmeyer flasks were filled to the 100-milliliter mark with this pond water. These three flasks were used as a control group. Two additional 200 milliliter Erlenmeyer flasks were filled to the 100-milliliter mark with the pond

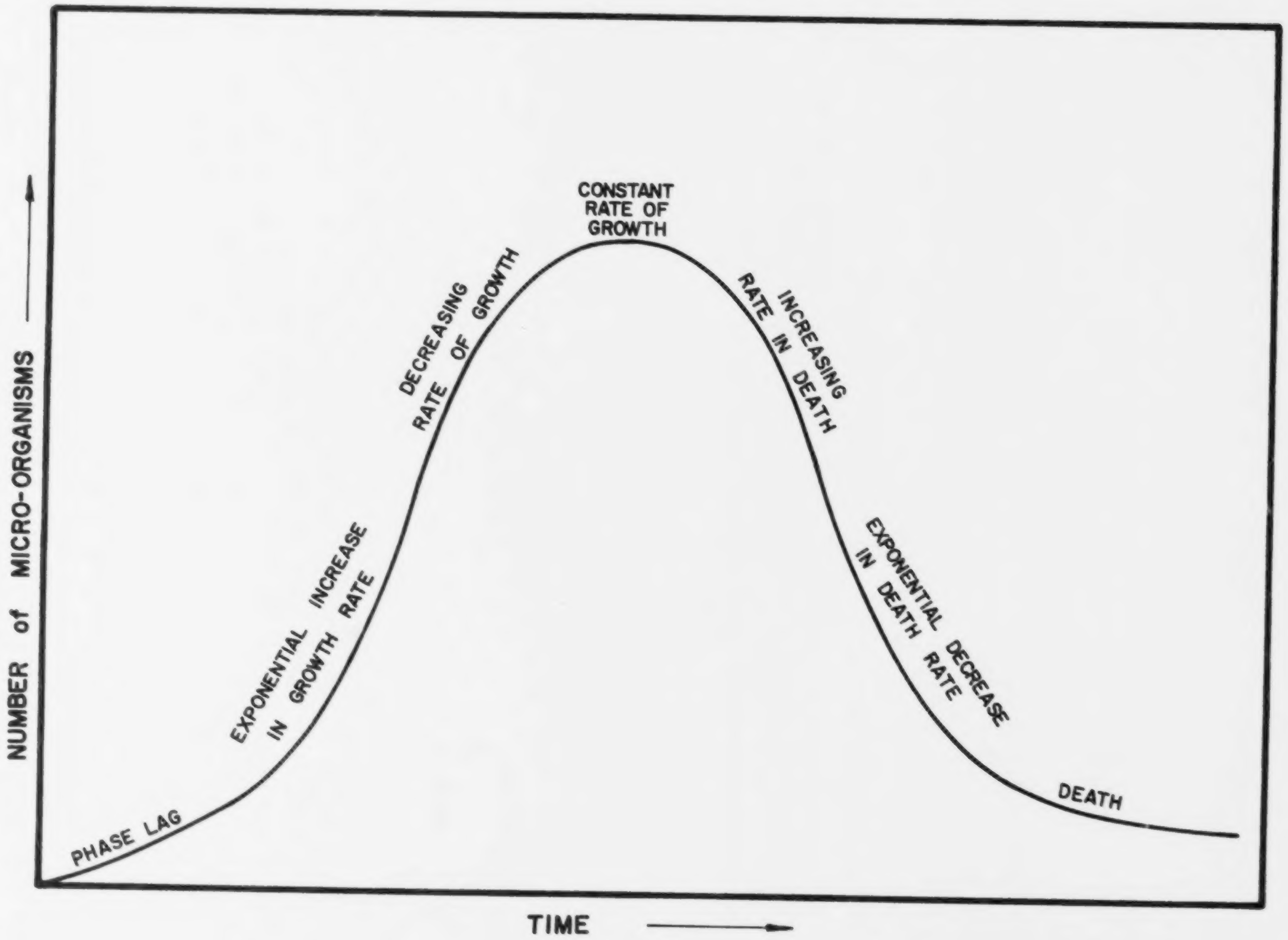


Figure 8. Theoretical Growth and Death Rate of Bacteria.

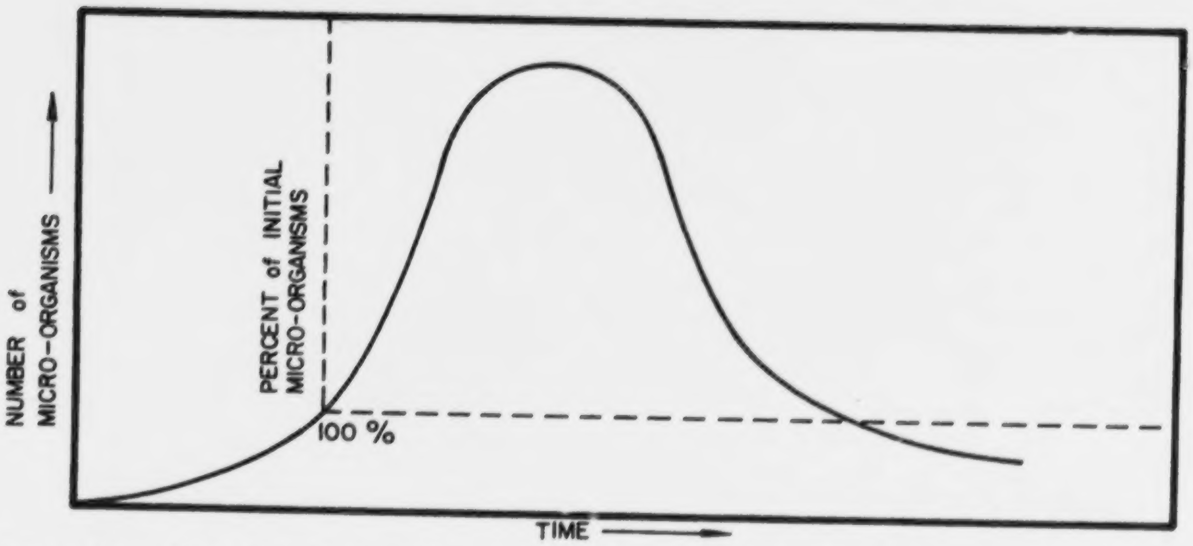


Figure 9a. Relationship of Initial Micro-Organisms to Time, Based on an Arbitrary Time on the Theoretical Growth and Death Curve.

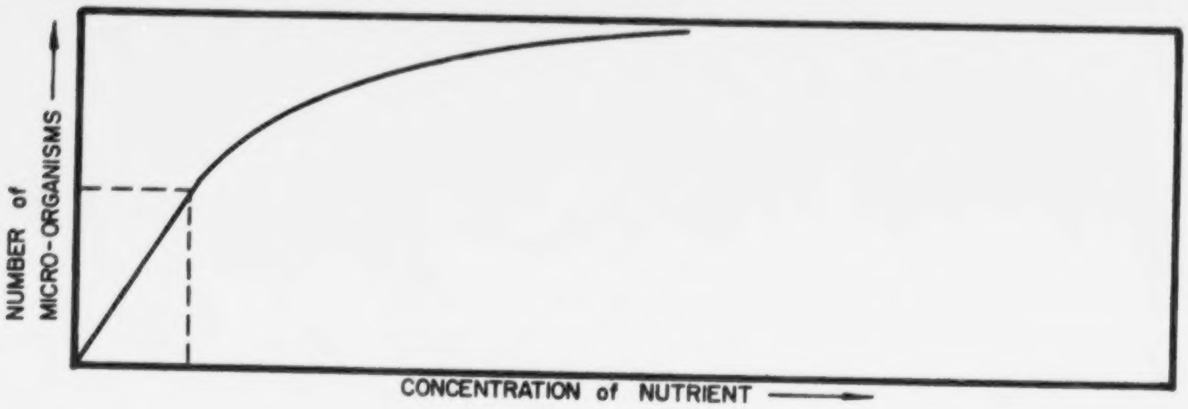


Figure 9b. Affect of Nutrient Concentration Upon Growth of Bacteria.

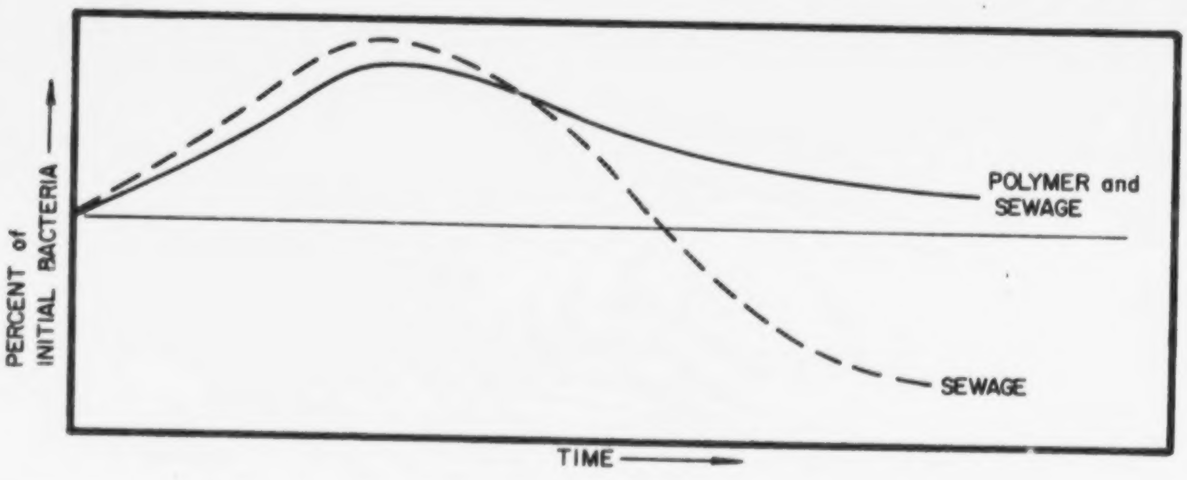


Figure 9c. Affect of Nutrient on Bacterial Count, With Respect to Time.

TABLE III

BIOLOGICAL TOXICITY TEST

Additive	Polymer Concentration (mg/1)	Average Bacterial Count by Percent							Temp. °C/°F
		Number of Hours from Start							
		0	3	6	9	24	48	72	
None	---	100	204	163	201	165	88	124	20.5/85
AP-30	100	100	190	142	137	99	147	98	29.5/85
WSR-701	100	100	179	142	136	123	95	112	29.5/85
WSR-301	100	100	202	170	122	115	117	75	29.5/85
FR-4	100	100	178	155	125	137	116	94	29.5/85
J-2FP	100	100	167	170	140	112	98	81	29.5/85
D-252	100	100	162	135	130	140	104	90	29.5/85
++AP-30	100	100	214	168	140	147	151	141	29.5/85
++WSR-701	100	100	199	130	167	160	130	100	29.5/85
++WSR-301	100	100	220	158	153	168	152	107	29.5/85
++FR-4	100	100	137	158	210	179	125	117	29.5/85
++J-2FP	100	100	165	117	141	103	80	87	29.5/85
++D-252	100	100	148	116	155	97	90	90	29.5/85
None	---	100	120	157	166	40	18	18	29.5/85
AP-30	500	100	154	184	166	158	60	46	29.5/85
WSR-701	500	100	136	139	134	94	25	14	29.5/85
WSR-301	500	100	148	145	128	78	22	12	29.5/85
FR-4	500	100	152	134	114	108	103	76	29.5/85
J-2FP	500	100	158	105	124	164	53	52	29.5/85
D-252	500	100	153	140	121	107	58	27	29.5/85
++AP-30	500	100	178	84	117	104	148	120	29.5/85
++WSR-701	500	100	165	233	142	86	112	77	29.5/85
++WSR-301	500	100	161	166	156	81	85	90	29.5/85
++FR-4	500	100	141	144	120	65	131	59	29.5/85
++J-2FP	500	100	139	122	116	122	54	55	29.5/85
++D-252	500	100	203	175	164	116	175	92	29.5/85
None	---	100	89	63	59	63	33	69	2/35.6
AP-30	500	100	89	62	66	121	66	73	2/35.6
WSR-701	500	100	87	21	55	91	81	66	2/35.6
WSR-301	500	100	98	67	59	66	72	72	2/35.6
FR-4	500	100	82	59	62	60	72	62	2/35.6
J-2FP	500	100	75	70	68	81	70	67	2/35.6
D-252	500	100	80	61	65	73	71	72	2/35.6
++AP-30	500	100	77	63	54	87	83	59	2/35.6
++WSR-701	500	100	86	68	53	114	87	56	2/35.6
++WSR-301	500	100	74	46	44	81	82	77	2/35.6
++FR-4	500	100	89	54	60	94	68	62	2/35.6
++J-2FP	500	100	69	50	56	67	56	80	2/35.6
++D-252	500	100	74	41	68	106	68	52	2/35.6

++Denotes slurry (40% polymer, 59.5% cellosolve nonsolvent, 0.5% gelling agent, each by weight).

water, and a polymer was added to achieve the desired concentration. The flasks were then placed in a constant-temperature bath maintained between 23°C and 26°C (this temperature range approximated that of the pond where the samples were obtained). A 450-foot-candle light source was placed above the bath to maintain constant light intensity for photosynthesis. At selected time intervals, 1-milliliter samples were withdrawn from the Erlenmeyer flask and transferred to a microscopic slide for algae counting under a microscope equipped with a Whipple eye piece. Five random locations on the grid in the eye piece were counted and the results averaged.

The algae growth testing was conducted at two polymer concentrations (100 and 500 milligrams per liter) which provided an adequate range of conditions. The initial algae count of the pond water was considered to be 100 percent with subsequent algae counts, at specific time intervals, reported as deviations from the initial count and expressed as a percentage. An increase or decrease in algae count from the control group would indicate the nutrient or the toxicity affect of polymers on algae (Reference 3). Data from the testing of algae can be found in Table IV. Tests were also conducted on the nonsolvents to be used in producing slurries.

Fish Test and Analysis Procedure. The study of toxicity of polymers on fish was conducted with a test matrix involving three control groups for each polymer concentration. Tests were conducted at three polymer concentrations (50, 100 and 500 milligrams per liter), by using three samples at each polymer concentration.

A plastic swimming pool, five feet in diameter, served as a constant temperature bath, and temperature control was maintained by the cooling coils of a refrigeration unit. The temperature range was 20°C to 22°C, which approximated that of local pond water from which the guppies used were obtained. Each sample unit contained five guppies in 2.25 liters of the same pond water in which they were kept.

Toxicity effects of each polymer on the fish were evaluated by counting the fish still living at selected time intervals in the control group and in the test groups containing the polymers and the nonsolvents. The results were then reported as a percentage of fish remaining based on initial number of fish in the control group. Tabulated data can be found in Table V.

Bacteria Data Evaluation. In Figure 10, the combined data taken from Table III for the investigating period, indicates that minimal bacterial growth occurred in the sewage control at 48 hours. During this same test period higher counts of bacteria were obtained in the polymer-sewage mixtures. The data indicates that the bacteria were using the polymer as a food source. Lower polymer concentrations influenced growth to the extent that the total quantity of food available was reduced. Temperature reductions simply lowered bacteriological activity, thereby reducing growth.

TABLE IV

ALGAE TOXICITY TEST

Additive	Polymer (Conc. #) (mg/l)	Average Algae Count by Percent					
		Number of Hours from Start					
		0	6	9	24	48	72
None	---	100	212.7	160.3	136.5	85.7	86.8
AP-30	100	100	207.1	128.6	64.3	78.6	71.4
WSR-701	100	100	321.4	150.0	92.8	42.8	114.3
WSR-301	100	100	150.0	121.4	71.4	57.1	50.0
FR-4	100	100	135.7	78.6	64.3	57.1	57.1
J-2FP	100	100	185.7	92.8	100.0	142.8	114.3
D-252	100	100	207.1	114.3	78.6	42.8	35.7
AP-30	500	100	185.7	114.3	100.0	64.3	71.4
WSR-701	500	100	157.1	164.3	221.4	200.0	164.3
WSR-301	500	100	285.7	135.7	285.7	107.1	64.3
FR-4	500	100	221.4	71.4	221.4	71.4	28.6
J-2FP	500	100	164.3	128.6	150.0	57.1	57.1
S-252	500	100	244.4	211.1	133.3	66.7	77.8
Cellosolve	100	100	122.2	133.3	100.0	155.6	100.0
Cellosolve	500	100	111.1	100.0	88.9	155.6	100.0
Isopropanol	100	100	133.3	77.8	188.9	44.4	33.3
Isopropanol	500	100	111.1	66.7	77.8	111.1	44.4

Concentration

TABLE V

FISH TOXICITY TEST

Additive	Polymer Conc. ‡ (mg/l)	Average Fish Count by Percentage Remaining									
		Time (Number of Hours from Start)									
		0	6	12	24	30	36	48	54	60	72
None	---	100	100	100	100	100	100	96	96	96	96
AP-30	50	100	100	100	93	93	93	93	87	87	87
WSR-701	50	100	100	100	100	100	100	93	93	93	93
WSR-301	50	100	100	100	100	100	100	100	100	93	93
FR-4	50	100	100	100	93	87	87	87	87	87	87
J-2FP	50	100	100	100	100	100	100	100	100	100	93
D-252	50	100	100	100	100	100	100	100	100	100	100
None	---	100	100	100	100	100	100	100	100	100	93
AP-30	100	100	100	100	100	100	100	100	100	100	100
WSR-701	100	100	100	100	100	100	100	100	100	100	100
WSR-301	100	100	100	100	100	100	100	100	100	100	100
FR-4	100	100	100	100	100	100	100	100	100	100	100
J-2FP	100	100	100	100	100	100	100	100	100	100	100
D-252	100	100	100	100	100	100	100	100	100	100	100
None	---	100	100	100	100	100	100	100	100	100	93
AP-30	500	100	100	87	67	67	67	60	60	60	60
WSR-701	500	100	100	100	93	93	93	87	87	87	87
WSR-301	500	100	100	100	100	100	100	100	100	100	100
FR-4	500	100	100	100	87	87	87	87	87	87	87
J-2FP	500	100	100	100	100	100	100	100	100	100	100
D-252	500	100	100	100	100	93	93	93	80	80	80
None	---	100	100	93	87	87	87	87	87	87	87
Cellosolve	50	100	100	100	100	100	100	100	100	100	100
Cellosolve	100	100	100	100	100	93	93	93	93	93	93
Cellosolve	500	100	100	100	100	100	100	100	100	100	93
Isopropanol	50	100	100	100	100	100	100	100	100	100	100
Isopropanol	100	100	100	100	100	100	100	100	100	100	100
Isopropanol	500	100	100	100	100	87	87	87	80	80	80

‡ Concentration

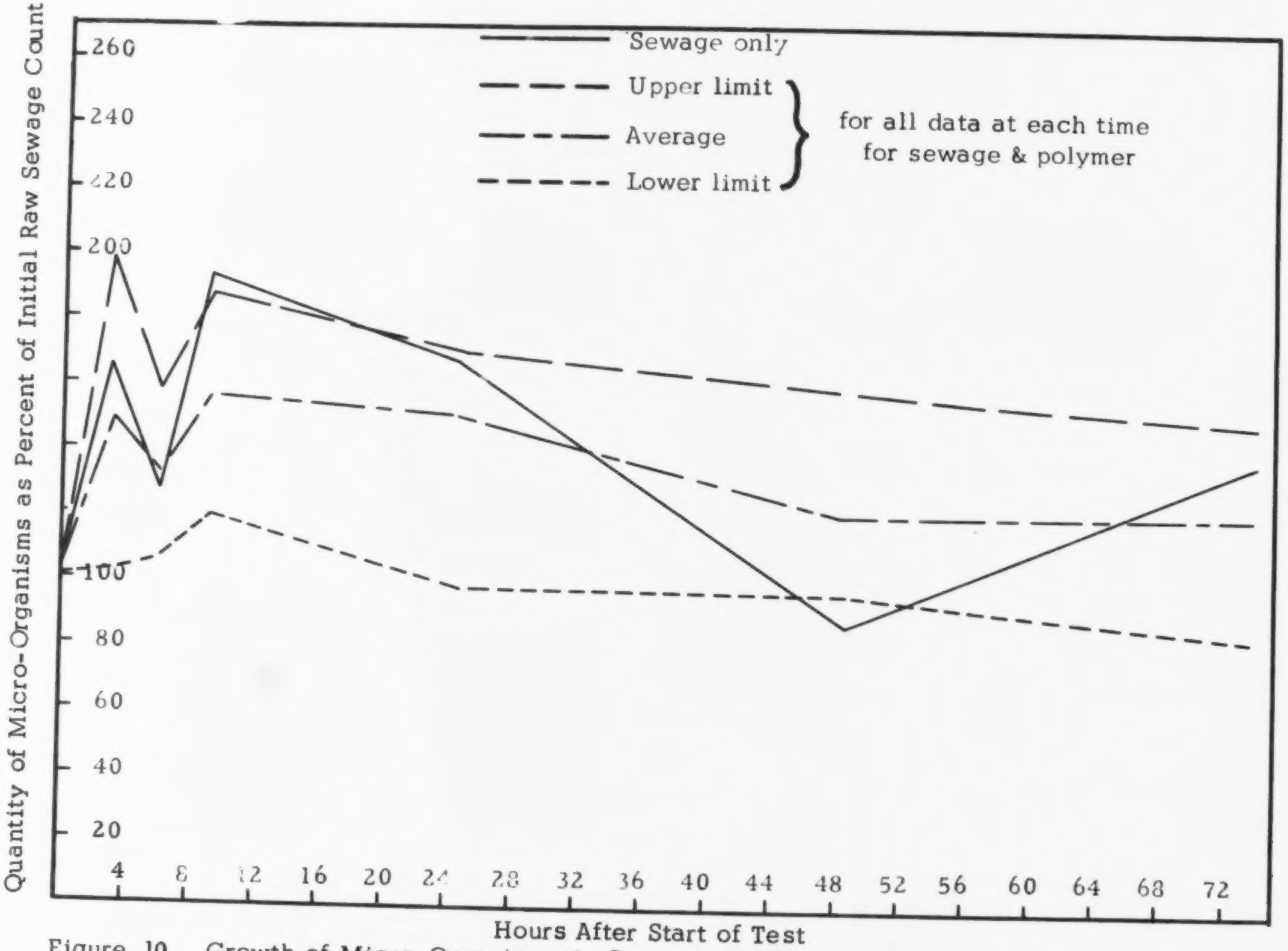


Figure 10. Growth of Micro-Organisms in Sewage and Polymer-Sewage Material Including Nonsolvents Used.

Comparative tests were made between polymers in the powdered form and in the slurry form. The nonsolvents, cellosolve and isopropyl alcohol, used in the slurried polymers proved to be generally nontoxic to bacteria in the magnitudes used. The slurry consisted of polymer (40 percent by weight), nonsolvent (59.5 percent by weight) and gelling agent (0.5 percent by weight).

The efficiency of sewage degradation by micro-organisms remains essentially unaltered when polymers are present. The tests proved that the polymers evaluated are nontoxic to the bacteria under the conditions of the tests. Thus, polymer injection into a sewer system should not be detrimental to the micro-biological treatment process in a sewer treatment plant.

Algae Data Evaluation. The curves in Figure 11 are taken from the combined data in Table IV. The trend is similar to that shown in Figure 10. There is only a slight deviation of the average combined data curve from the sewage curve; therefore, the polymers tested have no toxic or nutrient affect on algae under the concentrations and conditions tested.

Since the polymers tested are nontoxic and do not serve as a nutrient to algae, polymer injection into a surcharged sewer should have no undesirable affect upon algae in a lagoon, lake or stream after discharge as the effluent from a sewage treatment plant. Also, if polymer injections are used in storm sewers, the discharge should have no appreciable affect on the algae of the receiving waters.

Fish Data Evaluation. The data in Table V indicates a non-toxic affect of the polymers tested upon guppies used as subjects in the fish evaluation. There was a slight lowering in the percentage of fish remaining at a polymer concentration of 500 milligrams per liter; however, these values are within the realm of probability of natural deaths for the fish although it appeared that some of the polymers had a tendency to clog the gills.

Data for nonsolvents (cellosolve and isopropyl alcohol) used in the test program were included because polymer injection will usually be conducted by using slurries. The largest percentage, by weight, of a slurry consists of a nonsolvent, and the possibility exists that the nonsolvent might have deleterious affects upon marine life; however, data acquired during the environmental study show no appreciable toxic affects upon fish as the result of nonsolvents applicable to this program under the conditions of the tests. Therefore, the use of polymers as friction reducers in sanitary sewers will not contribute indirectly to lake or stream pollution by having a toxic affect upon fish life.

Polymer-Nonsolvent Slurry System Study

Slurry Formation. Water-soluble polymers dissolve readily in water; however, the solvation process involves thoroughly dispersing the individual resin particles during the first two or three minutes. As the polymer surfaces begin absorbing the solvent, they become very cohesive. Upon contact of the particles during this wet-out period, an agglomerate is formed

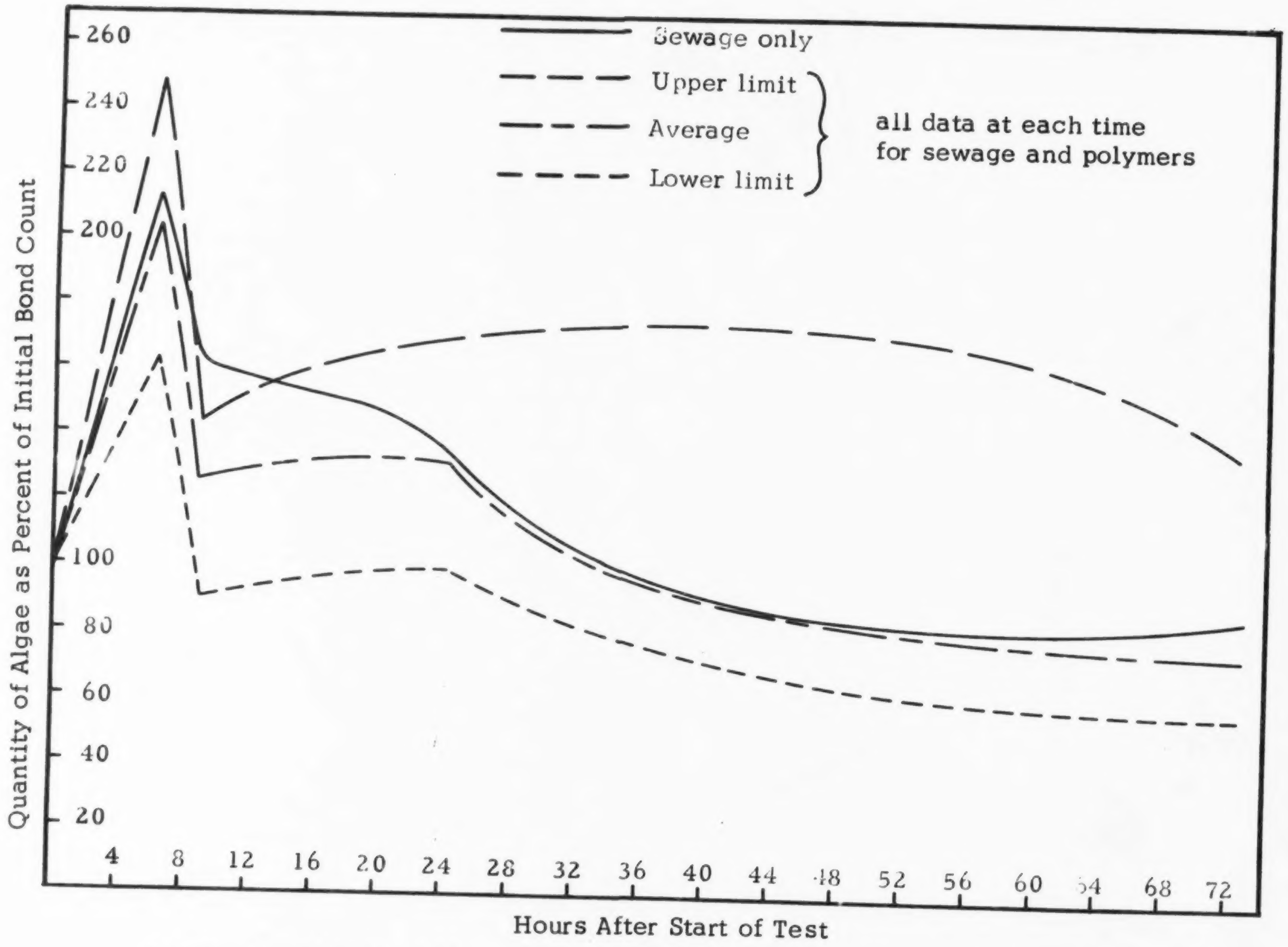


Figure 11. Growth of Algae in Sewage, and in Polymer-Sewage Media.

and prolonged agitation is required to dissolve the agglomerate or gell-like mass. By keeping the particles separated, the particle surface quickly dissolves, producing a protective envelope or film of viscous solution around the particle. The particle solvation proceeds with the solution viscosity increasing rapidly.

Since dispersion is necessary to enable the resin particles to be quickly and completely dissolved, a method is required to maintain polymer dispersion for the solvation process. Predispersion, of polymers in a nonsolvent that has been gelled, meets this criteria. Cellosolve (ethylene glycol monoethyl ether) gelled with a cellulose ether is an effective system for slurry formation of AP-30, FR-4 and J-2FP.

Anhydrous isopropanol gelled with a cellulose ether has shown to be an effective system for slurry formation of polyethylene oxides (WSR-301 and Polyox Coagulant-701.

The dispersion of polymers in slurry form can be prepared readily, stored for long periods and used as needed. These slurries, when added to water, form aqueous systems quickly and with minimum agitation, and are useful for large-scale operations where speed is necessary in getting the polymers dissolved quickly.

One polymer, D-252, would not lend itself to predispersion in a gelled nonsolvent. The incompatibility was due to a double convex particle shape which prevented a 40-percent polymer loading in the gelled nonsolvent (cellosolve). Settling occurred in this suspension and the slurry was not easily pumped.

Slurry Degradation. Since polymers are known to degrade in aqueous systems, there existed a possibility that degradation might occur in the slurry system.

Degradation implies polymer chain scission and is reflected by a reduction in molecular weight of the polymers. Polymer chain cleavage is effected by mechanical agitation, by ultraviolet light, by bacteriological action, and by chemical oxidation due to dissolved air.

Reduction of molecular weight due to polymer chain scission is evaluated by measuring a reduction in the aqueous solution's viscosity.

In this study a weighed quantity of the desired polymer in slurry form was added to a weighed quantity of tap water to give a concentration of polymer at 500 ppm. This concentration of polymer was chosen, since the time required to measure the relative viscosity was less than three minutes per sample, which minimized experimental error due to degradation in the aqueous system. At the end of the first 24 hours of combined materials, the polyacrylamides degraded by 0.52 percent and polyethylene oxides degraded by 4.1 percent. Thus, a measure of the relative viscosity of a freshly made aqueous polymer solution from a slurry would show if cleavage of polymer chain or degradation occurred to the polymer while stored in slurry form.

In the evaluation procedure, a 12-milliliter sample of the polymer test solution was introduced into a Ubbelohde Viscometer and the time of passage for this quantity of aqueous polymer solution obtained. The experiment was conducted in a constant temperature bath of 75°F, with the test solution being equilibrated prior to the time measurement was taken in the Ubbelohde Viscometer. The relative viscosity measurements obtained were defined as the ratio of time for the aqueous polymer solution (12 milliliter) to flow to the time for tap water (12 milliliter) to flow in the Ubbelohde Viscometer. The experimental error expected for relative viscosity measurements in the Ubbelohde Viscometer was ± 10 percent. From Figure 12, the plot of relative viscosity versus time implies no appreciable degradation occurring to polymers in a slurry form. The percents of error based on the average of relative viscosity measurements (shown in Table VI), taken over a 50-day period for AP-30, FR-4, Polyox Coagulant-701 and WSR-301, were recorded as 6.3 percent, 2.9 percent, 1.4 percent, 7.2 percent and 2.9 percent, respectively. This range is well within the expected experimental error of relative viscosity measurement.

TABLE VI

PERCENT ERROR IN VISCOSITY DETERMINATIONS

Polymer	Relative Viscosity	Average Relative Viscosity	Deviation	Average Standard Deviation	Precision
AP-30	3.502	3.443	-0.0594	.216	6.3
	3.708		-0.2654		
	2.118		+0.3246		
FR-4	2.770	2.897	+0.1270	.0847	2.9
	3.013		-0.1160		
	2.908		-0.0110		
Polyox Coagulant-701	2.290	2.0746	-0.2154	.1485	7.2
	2.082		-0.0074		
	1.852		+0.2226		
WSR-301	1.851	1.7886	-0.0624	.0525	2.9
	1.805		-0.0164		
	1.710		+0.0786		

Effect of Polymers on Sewage

Purpose of Tests. Evaluation of polymer affects on sewage was enabled by measurements of those parameters that produced the most significant information, e.g., dissolved oxygen, biochemical oxygen demand,

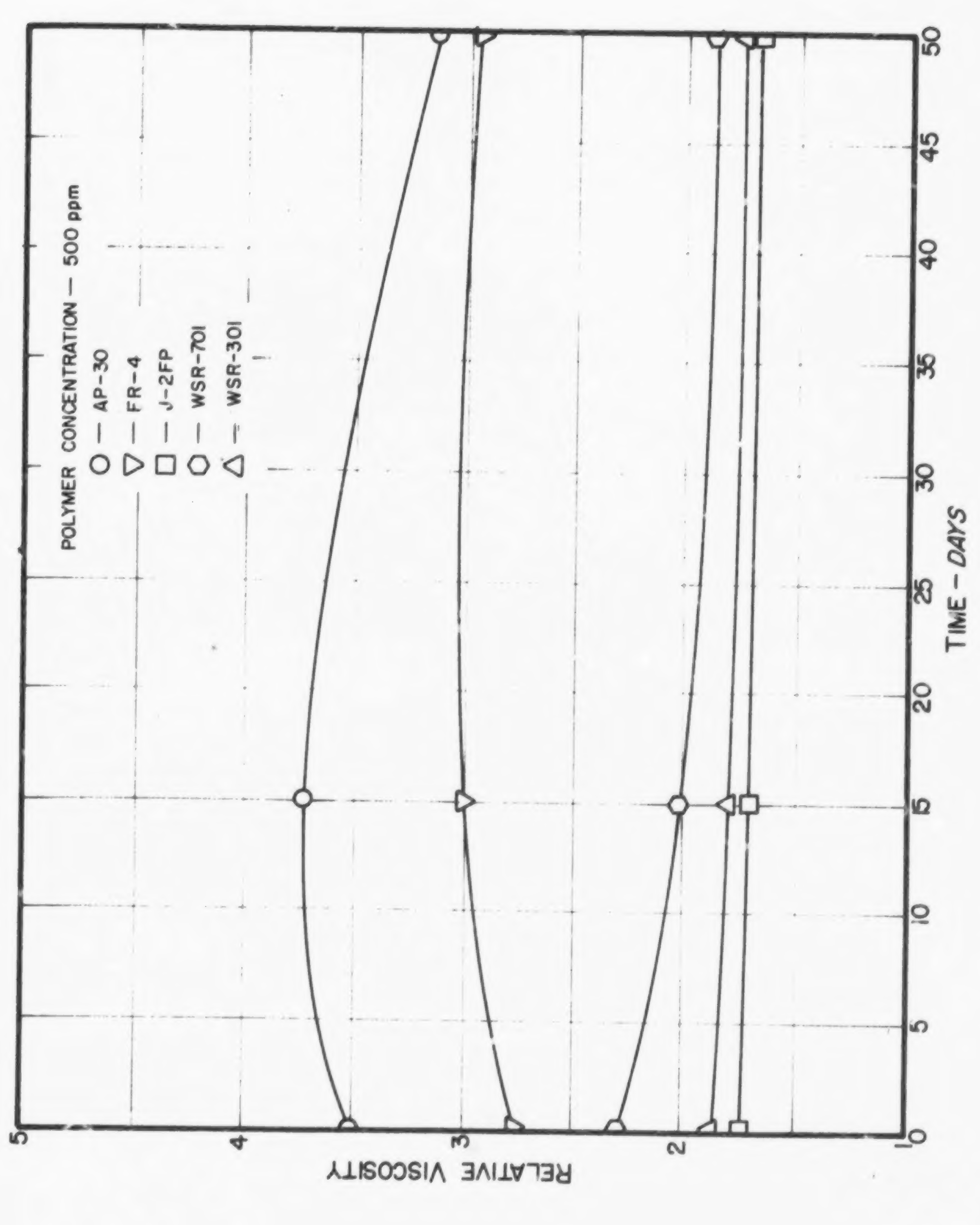


Figure 2. Degradation of Polymers in Slurries.

change in settleable solids, percent moisture change in sludge drying beds, total solids in sludge drying beds, and volatile solids in sludge drying beds.

Sedimentation Test and Analysis Procedure. Information, obtained from suppliers of the six selected polymers indicated that each polymer had the ability to settle inorganic and organic material--they all exhibited a varying ionic character that was pH dependent, which allowed them to be generally classified as polyelectrolytes. (Note: The exact mechanism by which the polymers agglomerate the suspended material is not known but, once formed, it should exhibit a strong bond and be quickly and irreversibly formed).

To determine the increase in sedimentation by polymer addition, a 1-litter graduated cylinder was filled to the mark with raw sewage (from the Rowlett Creek sewage treatment plant) for use as a control. At the same time, three 1-liter graduated cylinders were filled with the raw sewage and enough polymer was added (by weight) to obtain polymer concentrations of 100, 200 and 500 milligrams per liter. These samples were used to determine the magnitude of settling of the polymers, so that sewage settling could be determined.

A standard two-hour settling time was used for each graduated cylinder containing sewage, polymer/sewage and polymer/distilled water. Then, all but 100 milliliters were decanted from each cylinder, leaving essentially the settleable solids, and some water to be evaporated on a water bath. After evaporation to dryness, the solids were weighed and the milligrams per liter of settleable solids determined.

For analysis, the amount of polymer that settled in distilled water was subtracted from the amount of sewage and polymer that settled. This difference left the net quantity of sewage settled by the polymer. This quantity was then divided by the quantity of sewage that settled in the control, with the results expressed as a percentage. Values greater than 100 percent indicated an increase in sedimentation due to the addition of polymers.

Biochemical Oxygen Demand (BOD) Test and Analysis Procedure. Standard Methods (Reference 2) were used to determine biochemical oxygen demand (BOD) and dissolved oxygen (DO).

It has been shown that the polymers, being carbonaceous organic materials, are usable as a source of food by micro-organisms and, therefore, exerted an oxygen demand. Adequate DO is required for aerobic degradation of sewage, whether it takes place in sewer lines, in sewage treatment plants, or in effluent receiving waters.

Since polymers are degraded by both chemical oxidation and bacterological action, measurement of the DO will allow establishment of the oxygen requirements for polymers. By using 500 milligrams per liter concentrations, which are above the upper limit to be used, an extreme limit of oxygen use by the polymers was provided.

The standard BOD provides data for measurement of the stabilization of the oxidizable organic polymer systems.

Sludge Test and Analysis Procedure. A principal by product of sewage treatment is sludge. One method of disposal is to pump the digested sludge onto drying beds where it dries by drainage and/or evaporation. Since the polymer agglomerates the solid material in sewage, the resulting treated sludge may contain some of the polymer following an injection into a sewer line or prior to a plant function. By measuring the moisture content, the total solids, and the volatile solids, effects of the polymer on the sludge drying beds may be determined. Figure 13 shows the schematic arrangement and sizes of the test bed system used in evaluation of polymer affects on sludge drying.

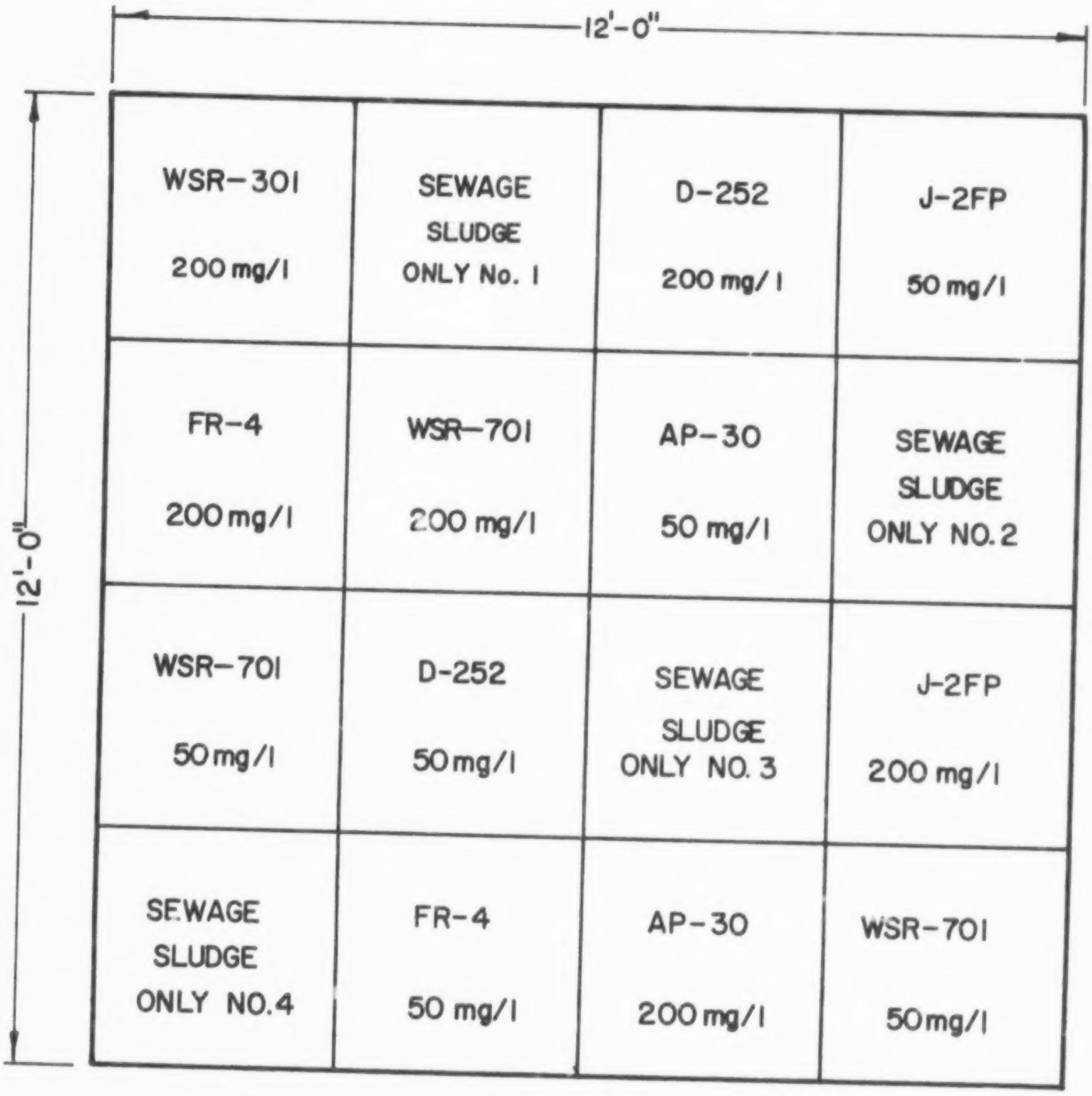
The drying bed, constructed of 2-inch by 12-inch lumber, was placed on an existing underdrained sludge bed to a depth of 2 inches. A 55-gallon barrel, fitted with a quick-closing/opening valve, was used as a mixing chamber. Enough polymer to prepare a 50- and a 200-milligram-per-liter concentration was added to 40 gallons of sludge, mixed and then drained onto one bed of the form. Four test beds of raw sludge were used as controls plus one bed for each polymer at each of the concentrations. In addition, a full-size sludge bed was filled with the same sludge at the same time the test beds were filled. Over a 28-day test period, 12 samples were taken from each of the test beds at specific time intervals. The moisture content was determined (by weight difference, before and after it was dried) and expressed as percent moisture. Other samples of 100-milliliter size were evaporated over a water bath according to standard methods (Reference 2) for total solids determination. The total solids samples were also used in determining the total volatile solids.

Sedimentation Data Evaluation. In Figure 14, the combined sedimentation data from Table VII for all polymers at varying concentrations indicate sedimentation capability; however, it should be noted that the percentage increase in sedimentation is dependent upon increases in polymer concentration. Figure 15 shows the order of sedimentation ability for each polymer at different concentrations.

Some loss of polymer may occur following injection into a sewer due to sedimentation; however, since injection will only be done when the sewer is surcharged, turbulence will keep the solids in suspension, and most of the polymer injected will be available for energy reduction and for the accompanying possible increase in settling of solids in the treatment plant.

BOD Data Evaluation. A maximum polymer concentration of 500 milligrams per liter was chosen for the BOD determination because magnitude was not of any great importance with respect to the sewage BOD (smaller concentrations of polymers would be even of less importance in the sewer systems).

Based on the standard BOD test, Table VIII indicates that the biochemical oxygen demand for all polymers is 1.56 milligrams per liter for a polymer concentration of 500 milligrams per liter. Essentially, this value



WSR-301 200 mg/l	SEWAGE SLUDGE ONLY No. 1	D-252 200 mg/l	J-2FP 50 mg/l
FR-4 200 mg/l	WSR-701 200 mg/l	AP-30 50 mg/l	SEWAGE SLUDGE ONLY NO. 2
WSR-701 50 mg/l	D-252 50 mg/l	SEWAGE SLUDGE ONLY NO. 3	J-2FP 200 mg/l
SEWAGE SLUDGE ONLY NO. 4	FR-4 50 mg/l	AP-30 200 mg/l	WSR-701 50 mg/l

Figure 13. Sludge Drying Test Beds.

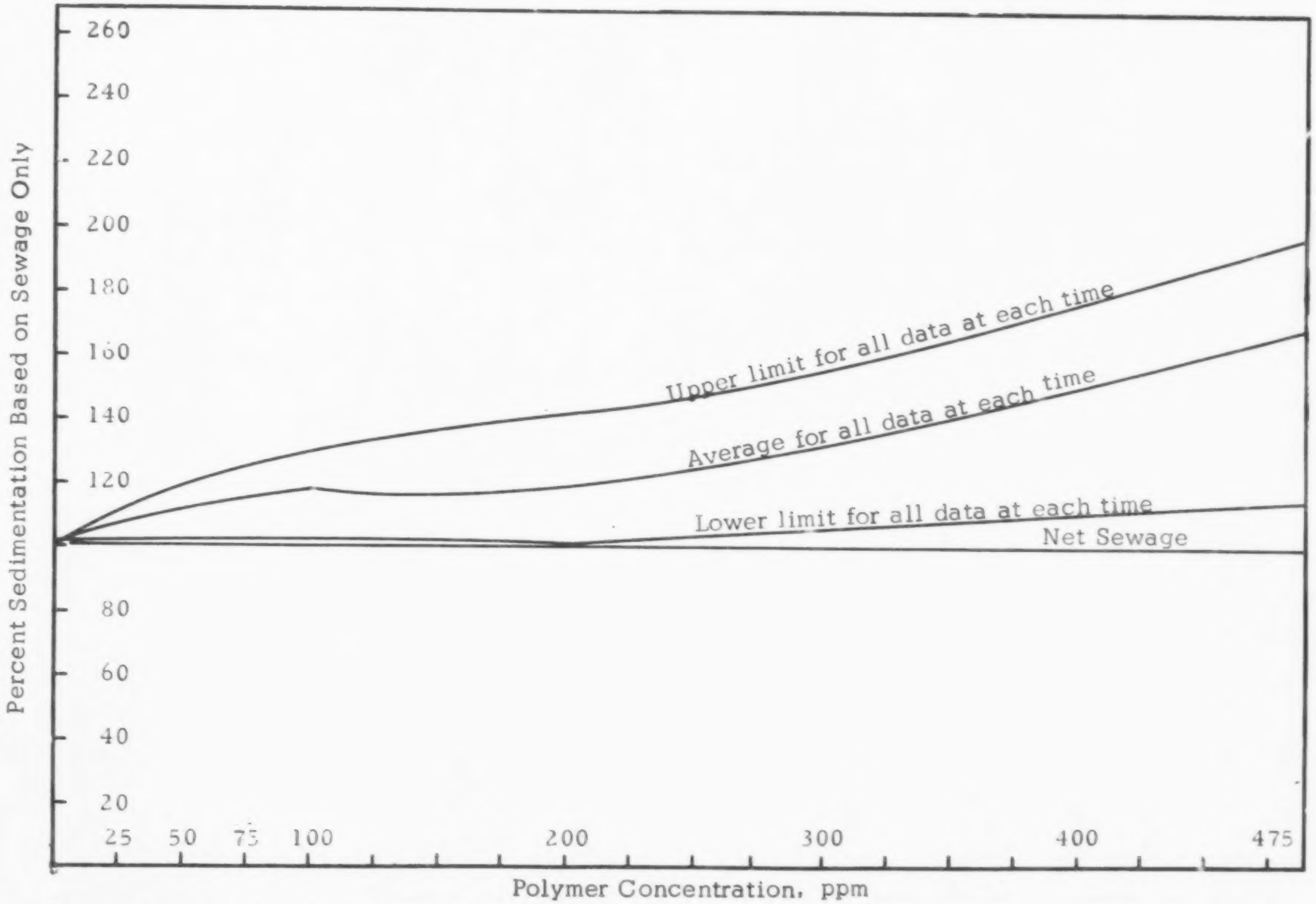


Figure 14. Sedimentation Capabilities of Polymer, Based on Percent Increase of Net Sewage Value.

TABLE VII

SEDIMENTATION CAPABILITY OF POLYMERS

Additive	Polymer Conc. # (mg/1)	Setteable Solids (mg/1)			
		Sewage & Polymer	Polymer	Net Sewage	Percent Net Sewage Only Results
AP-30	0	119	0	119	100
AP-30	100	172	9	163	137
AP-30	200	216	20	196	165
AP-30	500	269	34	235	197
FR-4	0	551	0	551	100
FR-4	100	730	68	662	120
FR-4	200	642	145	497	90
FR-4	500	886	265	621	113
D-252	0	89	0	89	100
D-252	100	144	50	94	106
D-252	200	195	91	104	117
D-252	500	367	214	153	172
J-2FP	0	122	0	122	100
J-2FP	100	163	46	117	96
J-2FP	200	204	45	159	130
J-2FP	500	399	69	330	270
WSR-301	0	86	0	86	100
WSR-301	100	162	49	113	131
WSR-301	200	236	126	110	128
WSR-301	500	448	313	135	157
WSR-701	0	276	0	276	100
WSR-701	100	---	---	---	---
WSR-701	200	295	41	254	92
WSR-701	500	368	43	325	118

Concentration

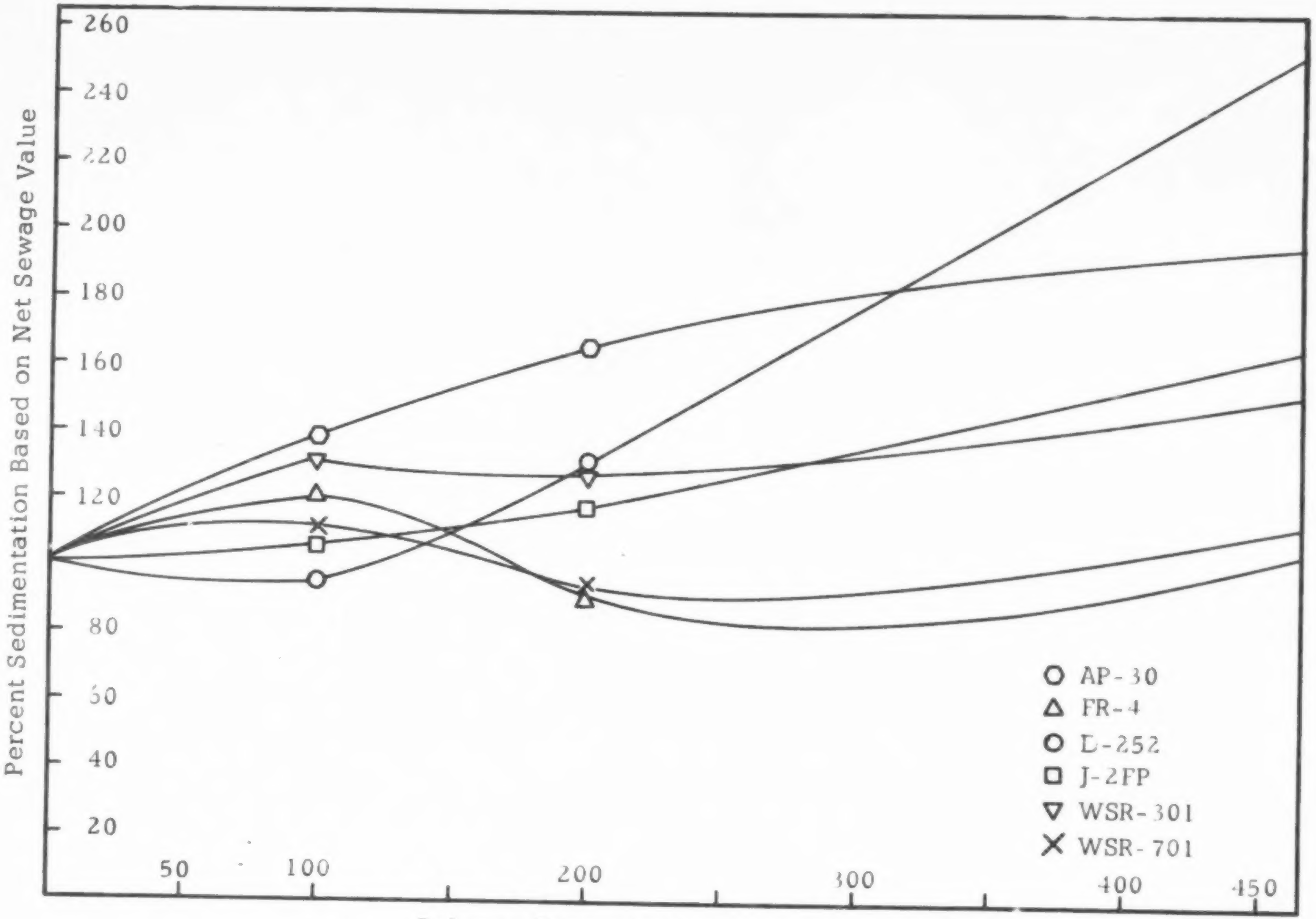


Figure 15. Sedimentation Capabilities of Polymer on Settleable Solids.

indicates a very slight increase in oxygen demand of polymer sewage mixtures when compared with the raw sewage used in these tests which is in the general range of 200 milligrams per liter.

TABLE VIII

BIOCHEMICAL OXYGEN DEMAND (BOD) OF POLYMERS

Additive	Polymer Concentration (mg/l)	DO at Start (mg/l)	DO at 5 days (mg/l)	BOD at 5 days (mg/l)	Temp. °C/°F
AP-30	500	7.70	6.25	1.45	20/68
FR-4	500	7.80	6.60	1.20	20/68
D252	500	8.20	6.35	1.85	20/68
J-2FP	500	8.20	5.70	2.50	20/68
WSR-301	500	7.60	5.75	1.85	20/68
Polyox - Coagulant-701	500	5.90	5.40	0.50	20/68

Sludge Data Evaluation. The sludge data in Tables IX and X were treated by the method of least squares and the results are plotted in Figures 16, 17 and 18. Figure 16 shows that, at the beginning of the test period, the percent moisture is lower in sludge alone than it is in sludge and polymer mixtures; however, as time progresses, the sludge-polymer mixtures have a much lower percent moisture value. From this data it is reasonable to assume that the polymers are beneficial in decreasing the water-retention capability of sludge; therefore, over a given time, yielding a dryer sludge cake for earlier disposal.

In studying Figures 17 and 18 for total solids and volatile solids, it is apparent that the polymers increase the total solids and volatile solids per unit of volume over the test period. Since the polymers help in moisture reduction, it is expected that with time, values for total solids and volatile solids would increase in the sludge drying beds.

TABLE IX

AFFECT OF POLYMERS ON SLUDGE DRYING BEDS

Polymer or Sample	Polymer Conc (mg/1)	Percent Moisture					
		Days from Start					
		0	1	3	7	14#	28
Sludge Bed	none	92.61	90.22	87.85	81.38	81.32	72.48
Sludge Only	none	93.16	90.58	87.68	76.10	77.21	60.65
AP-30	50	93.56	91.82	87.26	79.23	76.06	64.04
AP-30	200	93.55	90.90	87.45	71.03	74.38	65.44
FR-4	50	93.49	91.07	84.26	80.24	71.12	65.42
FR-4	200	93.76	91.91	87.56	76.98	72.80	58.97
J-2FP	50	93.52	91.16	88.68	80.08	71.42	66.24
J-2FP	200	93.49	91.64	87.94	71.98	71.30	32.33
D-252	50	93.02	90.67	88.50	79.31	72.85	48.48
D-252	200	93.81	92.23	88.46	82.39	74.06	30.76
WSR-301	50	93.59	91.63	87.06	81.40	76.59	51.74
WSR-301	200	96.67	91.74	88.77	81.38	75.67	40.78
WSR-701	50	93.54	91.48	88.74	74.20	71.42	30.20
WSR-701	200	92.74	91.70	89.09	81.49	75.45	61.69

NOTE: "Sludge bed" is an average of two readings taken from a large sludge bed.

"Sludge only" is an average of four readings taken from four tests beds.

#Rained during morning while samples were taken.

TABLE X

AFFECT OF POLYMER ON SLUDGE DRYING BEDS.

Polymer or Sample	Polymer Conc. (mg/l)	Total Solids (mg/l)						Volatile Solids (mg/l)					
		Days from Start						Days from Start					
		0	1	3	7	14*	28	0	1	3	7	14*	28
Sludge Bed	none	73,890	97,802	121,575	186,240	186,891	275,237	40,985	53,925	66,336	98,694	100,384	143,912
Sludge Only	none	68,357	94,219	123,192	239,024	254,421	393,423	37,395	49,293	67,765	128,549	135,700	170,918
AP-30	50	64,407	81,821	127,404	207,683	239,393	359,600	36,126	45,959	72,462	115,539	130,987	177,827
AP-30	200	64,550	90,963	125,468	289,653	256,245	345,625	36,288	50,360	68,652	160,272	145,744	191,269
FR-4	50	65,085	89,310	157,413	197,563	288,833	345,847	36,231	48,639	86,860	110,042	141,125	183,692
FR-4	200	62,366	80,888	124,419	230,243	272,033	410,309	36,132	45,324	71,406	131,037	155,260	223,349
J-2FP	50	64,775	88,376	112,981	199,154	285,808	337,634	36,904	43,787	63,218	112,685	157,824	182,389
J-2FP	200	65,088	83,558	120,636	280,235	287,042	676,737	36,101	46,451	63,768	155,429	158,027	366,549
D-252	50	69,769	93,298	115,005	206,862	271,467	515,176	39,178	51,715	65,131	118,007	145,766	287,044
D-252	200	61,948	77,681	115,441	176,125	259,409	692,403	35,466	44,649	66,222	98,898	140,732	386,643
WSR-301	50	64,150	83,750	129,367	185,955	234,145	482,570	35,548	46,338	72,160	100,134	130,648	253,583
WSR-301	200	33,328	82,545	112,316	186,219	243,339	592,230	7,166	47,344	64,754	107,985	150,182	327,966
WSR-701	50	64,567	85,204	112,641	258,005	285,809	697,951	35,517	47,081	62,213	137,807	157,722	379,466
WSR-701	200	72,586	83,001	109,123	185,052	245,490	383,103	41,730	46,802	61,816	105,686	133,404	201,867

NOTE: "Sludge bed" is an average of two readings taken from a large sludge bed.

"Sludge only" is an average of four readings taken from four test beds.

*Rained during morning while samples were taken.

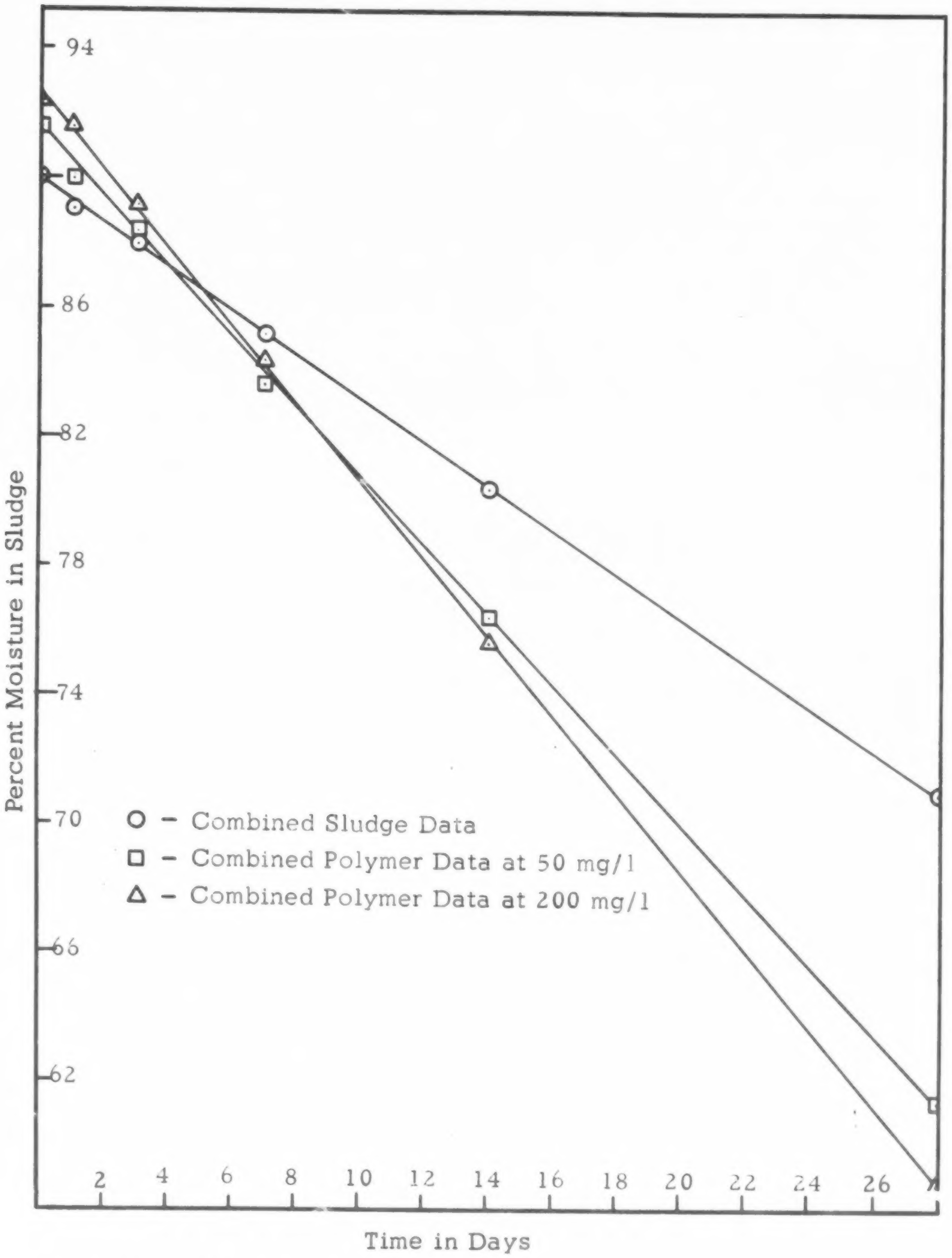


Figure 16. Affects of Polymers (at Different Concentrations) on Moisture Content of Sludge.

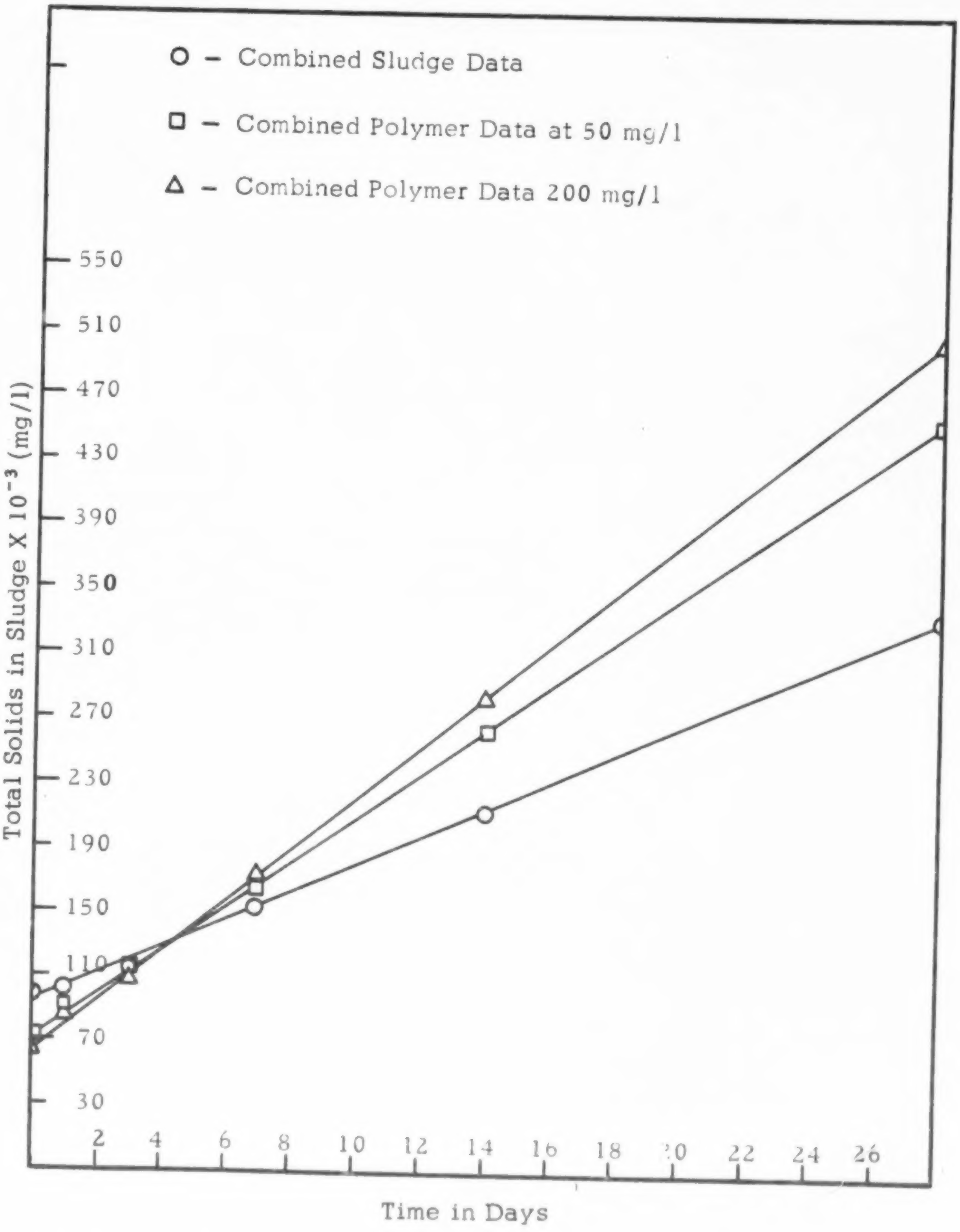


Figure 17. Affect of Polymers (at Different Concentrations) on Total Solids Content of Sludge.

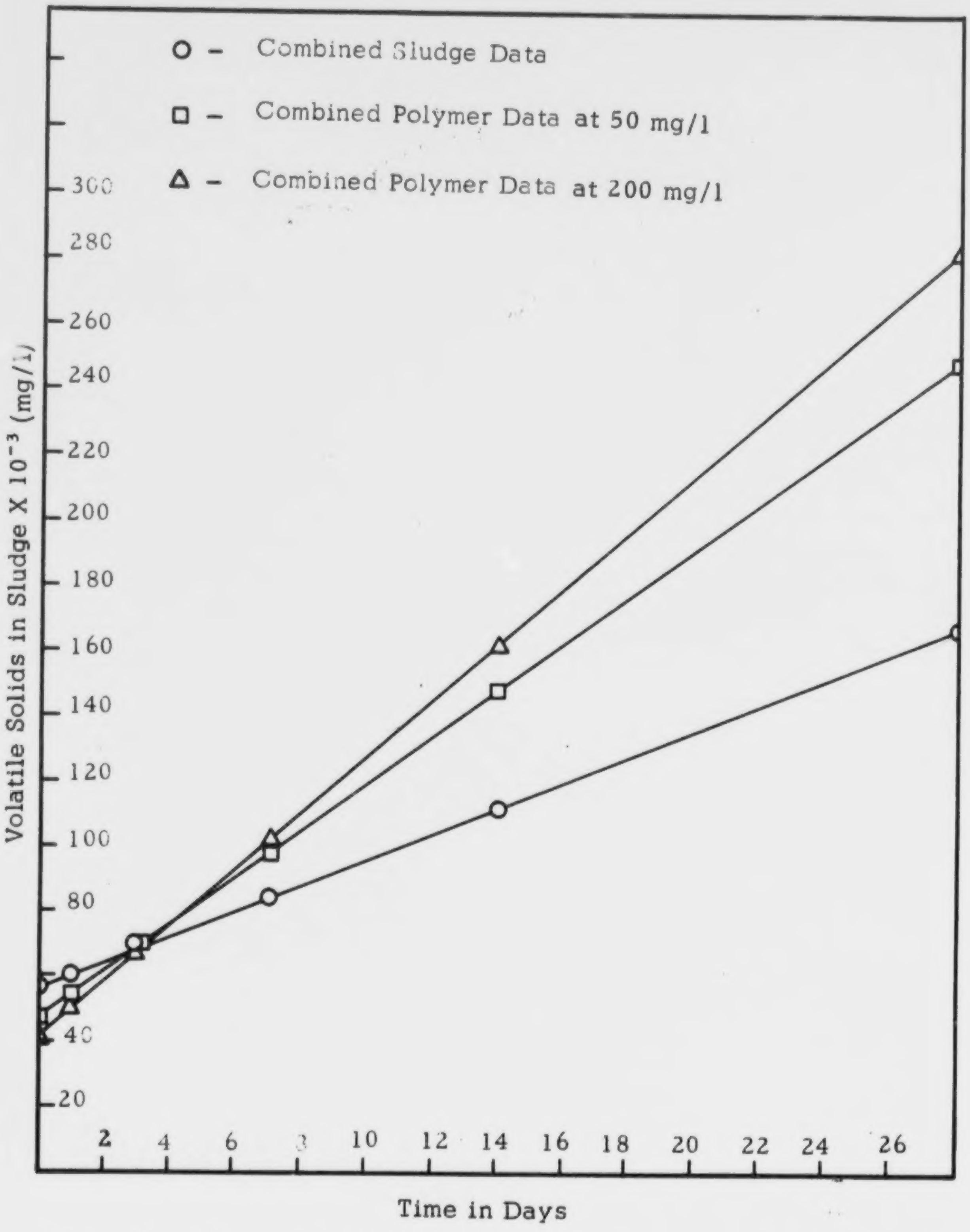


Figure 18. Affect of Polymers (at Different Concentrations) on Volatile Solids Content in Sludge.

SECTION IV

FLOW-TEST EVALUATION OF POLYMERS

Flow testing for additional evaluation of the six polymers previously selected was conducted in a six-inch diameter test sewer designed initially to provide a means of testing the polymers, both as surcharged closed-conduit flow and open-channel flow.

In addition, the same facility was used with a four-inch diameter line for the establishment of injection locations in a line to optimize the operation with respect to the hydraulic cause of the surcharging of a line.

Description of Flow-Test Facilities

Six-Inch Diameter Sewer. A 100-foot-long section of six-inch asbestos-cement and transparent plastic sewer pipe was constructed to evaluate the effects of different energy-reducing polymers on sewage under different flow conditions. The facility (see Figure 19 for a schematic drawing) was constructed so that the following parameters could be varied to provide the variations in flow characteristics needed in the program.

TABLE XI

TEST FLOW PARAMETERS

Parameter	Range
Temperature, ^{0}F	38 - 90
Slope, percent	0.3 - 2
Flow Rate, gpm	0 - 750
Polymer concentration, mg/l	0 - 1,500
Sewage concentration, ml/l	As required

The temperature of the water or sewage used in the test program was controlled by a combination heating and cooling recirculation system. The heating system was a 800,000 btu per hour output boiler designed to heat 22,500 gallons of sewage from 65^{0}F to 90^{0}F, in 8 hours. The refrigeration system consisted of four 15-ton cooling units and one 25-ton cooling unit operated in series with a total system output of 85 tons (1,020,000 btu/hr.) which was sufficient to cool 22,500 gallons of sewage from 70^{0}F to 38^{0}F in 12 hours. The lowest testing temperature was established as the temperature at which icing would not occur in the evaporators, and thereby prevent possible damage to the units and a delay in the test program.

The slope of the test pipe could be adjusted to obtain a maximum of a two-percent flow-line slope. To accomplish this, the entrance of the sewer line was fixed and the line was mounted on an I-beam which was supported every 20 feet by a vertically adjustable base. The span and shape properties of the I-beam were such that the flow line of the pipe would not deflect more than 0.08 inch under the maximum live and dead load anticipated. The slope of the line during testing was established by using an engineer's level.

The sewage flow was accomplished by the use of a Marlow, Model 4C7 centrifugal pump driven by a gasoline engine which was fitted with a gate valve for flow rate control. Flow rates up to 750 gallons per minute could be achieved by varying the engine revolutions per minute and/or the gate valve opening.

The polymer concentration in the sewage was achieved by pumping a concentrated polymer slurry from a 1,000-gallon storage tank into the sewage with a variable volume, positive displacement pump capable of pumping at rates from zero to 175 gallons per minute. The flow rate of the concentrated polymer solution was determined from a calibration curve of pump output versus the pump vernier scale reading. The injection of the polymer occurred ahead of the test sewer section at variable rates capable of providing concentrations of 0 to 1,500 milligrams per liter in the sewage.

Sewage concentration was measured as a function of settleable solids in terms of milliliters per liter. To facilitate the addition of concentrated sludge (obtained from a local treatment plant) to water in the 22,500-gallon reservoir, a diaphragm pump was used to transfer the sludge from the transport truck. During this manufacturing process, the 4-inch gasoline driven centrifugal pump was used to provide homogeneity by using a recirculation loop. Sampling ports were provided to various locations along the sewage reservoir to facilite sample withdrawal for chemical analysis.

A 30-foot section of the 100-foot conduit was chosen for measurement. This measurement section was located 100 pipe diameters (50 feet) downstream of the line entrance. The 100-pipe-diameter approach length was provided to insure that all entrance affects had been suppressed and that full turbulent flow had been established. The length of the test section was determined to allow the flow to be analyzed over three pipe sections. This minimized the affect of the pipe joints and gave pressure drops of sufficient size to be read easily. Two sections upstream from the test zone, a transparent section was installed for visual observation of the additive mixing with the sewage.

The six-inch test facility was instrumented to provide the data and ranges indicated in Table XII.

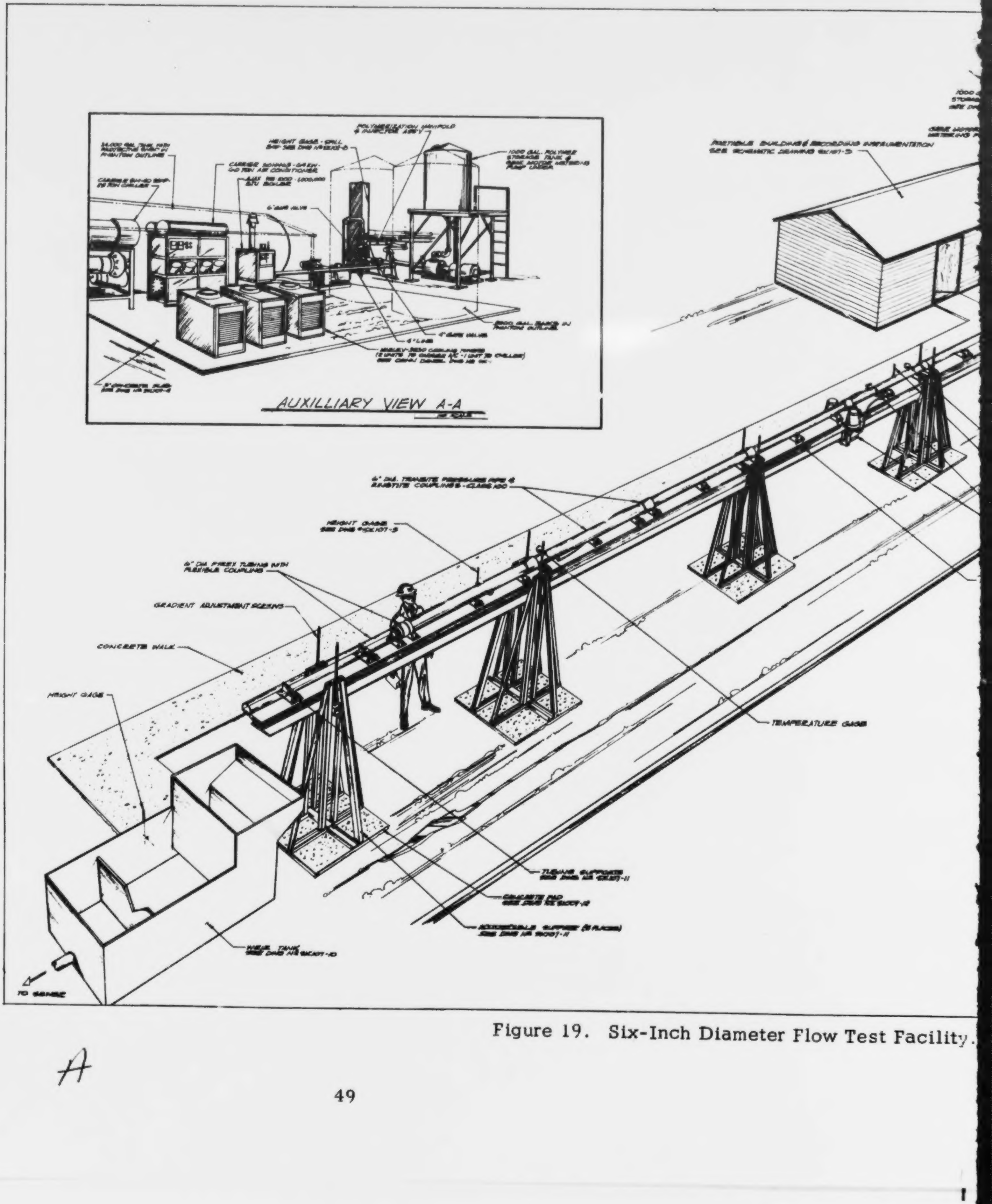
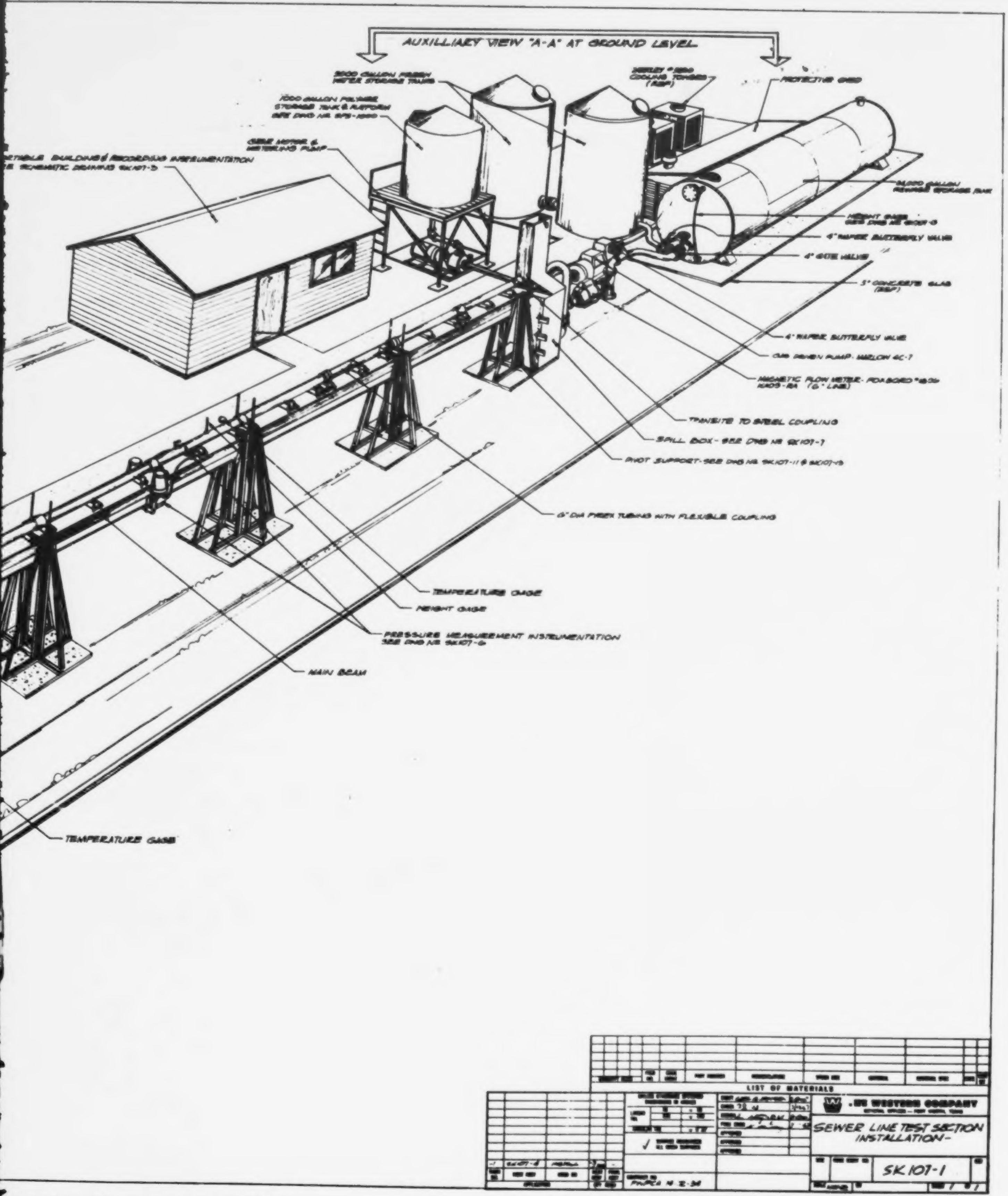

AUXILLIARY VIEW A-A
POLYMERIZATION MANIFOLD & INJECTOR ASS'Y
HEIGHT GAGE - SPILL BAY
1000 GAL. POLYMER STORAGE TANK
PHANTOM OUTLINE
60 TON AIR CONDITIONER
BOILER
6" GATE VALVE
4" GATE VALVE
6" LINE
COOLING TOWERS
PHANTOM OUTLINE
PORTABLE BUILDING & RECORDING INSTRUMENTATION
6" DIA. TRANSITE PRESSURE PIPE & RINGTITE COUPLINGS - CLASS 100
HEIGHT GAGE
6" DIA PYREX TUBING WITH FLEXIBLE COUPLING
GRADIENT ADJUSTMENT SCREWS
CONCRETE WALK
HEIGHT GAGE
TEMPERATURE GAGE
TUBING SUPPORTS
CONCRETE PAD
ADJUSTABLE SUPPORT
WEIR TANK
TO SEWER

Figure 19. Six-Inch Diameter Flow Test Facility.

A


AUXILLIARY VIEW "A-A" AT GROUND LEVEL
3000 GALLON FRESH WATER STORAGE TANKS
1000 GALLON POLYMER STORAGE TANK & PLATFORM SEE DWG NO. 875-1000
GEAR MOTOR & METERING PUMP
RTABLE BUILDING & RECORDING INSTRUMENTATION
E SCHEMATIC DRAWING SK107-3
COOLING TOWER (REF)
PROTECTIVE GRID
14,000 GALLON SEWAGE STORAGE TANK
HEIGHT GAGE SEE DWG NO. SK107-13
4" WAFER BUTTERFLY VALVE
4" GATE VALVE
5" CONCRETE SLAB (REF)
4" WAFER BUTTERFLY VALVE
GAS DRIVEN PUMP - MARLOW 4C-7
MAGNETIC FLOW METER - FOXBORO #1806 MAG3-RA (6" LINE)
TRANSITE TO STEEL COUPLING
SPILL BOX - SEE DWG NO. SK107-7
PIVOT SUPPORT - SEE DWG NO. SK107-11 & SK107-13
6" DIA PYREX TUBING WITH FLEXIBLE COUPLING
TEMPERATURE GAGE
HEIGHT GAGE
PRESSURE MEASUREMENT INSTRUMENTATION SEE DWG NO. SK107-6
MAIN BEAM
TEMPERATURE GAGE
LIST OF MATERIALS
SEWER LINE TEST SECTION INSTALLATION-
SK107-1

iameter Flow Test Facility.

B

TABLE XII

TEST PARAMETERS AND RANGES

Data	Range
Temperature, °F	0 - 200
Flow Rate, gpm	0 - 1,000
Static Pressure at Sewer Line Entrance, inches H_2O	0 - 60
Static Pressure at Start of 30-Foot Test Section, inches H_2O	0 - 205
Static Pressure Drop Across 30-Foot Test Section, inches H_2O	0 - 20

Three temperature indicators were used. One indicator was placed in the storage tank, one placed just prior to the 30-foot test section and one placed just after the 30-foot test section. The sensors used were Weston bimetal thermometers with an accuracy of ± 1/2 percent of the reading with the bulb directly immersed in the sewage flow.

A flowmeter was designed in the feed line following the primary pump. The flowmeter consisted of a six-inch Foxboro meter and transmitter (Type 1806-KAOS-RA) in conjunction with a Dynalog Electronic Recorder (Model No. 9650C) providing an overall flow measuring accuracy of ± 1 percent. As a system check, the effluent of the six-inch line emptied into a catch basin which contained a standard 90-degree V-notched weir.

The static pressure-head at the sewer line entrance was read through the use of a vertical sight glass marked every 0.0625 inches.

A pressure transducer was installed at the start of the 30-foot section (50 feet from sewer line entrance) to measure the static pressure at this point. The pressure monitoring system consisted of a Foxboro Model 613 DM differential pressure transmitter in conjunction with a Sargent Model SR recorder. This system provided readings ± 1 percent of full-scale transducer capability. The low side of the transducer was vented to atmospheric conditions.

Another pressure monitoring system similar to the above system was provided to measure the static pressure drop across the 30-foot test section.

Four-Inch Injection Point Effect Test Facility. A four-inch flow system was built from the six-inch facility reservoir, pump, flowmeter and the instrumentation. It was used to determine the most desirable distance upstream from a flow constriction at which polymers should be injected.

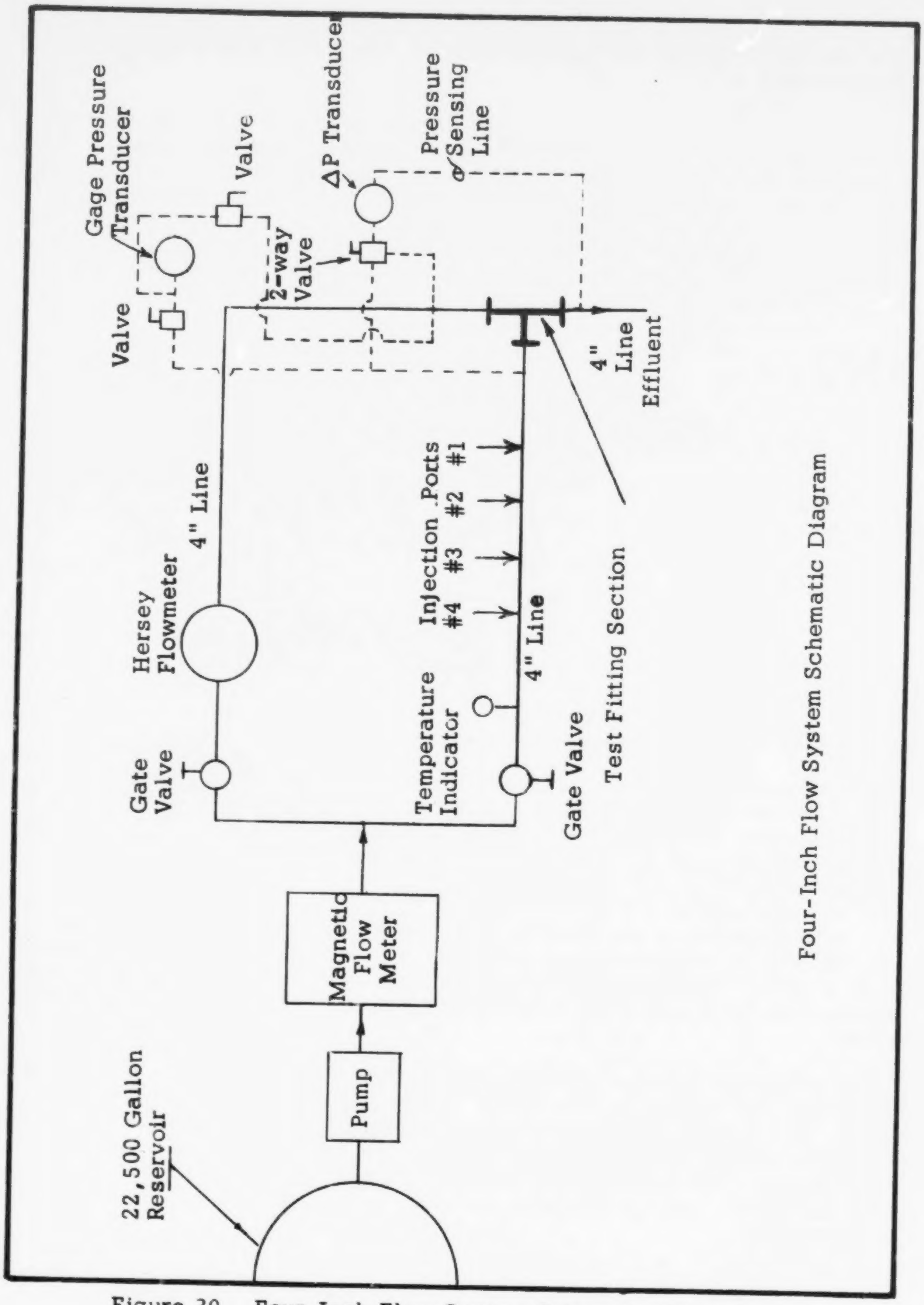
Two four-inch lines were manifolded from the flowmeter and provided with manual gate valves to regulate the flow in each line (Figure 20). One of the lines was fitted with a Hersey rotating disc flowmeter so that the flow in each line could be determined by a mass flow balance. The other line contained four injection points placed at distances of 7, 12, 17 and 22 feet upstream from the constriction formed by the junction of two 4-inch lines discharging into one 4-inch conduit and certain fittings. The same polymer injection technique was used as in the six-inch system. The system was designed to accommodate all the restrictions tested, including the circular cross-section long-radius ell, short-radius ell, tee and the wye, and the square cross-section wye. For testing the ells, provisions were made for cutting off the non-injection leg of the system. A transparent section was installed downstream of the seven-foot injection port so that visual inspection of polymer/sewage could be made. Pressure taps were installed five feet upstream and five feet downstream of the restriction so both static pressures and differential static pressures across the constriction could be monitored.

Flow Test Procedure

Sewage Preparation. The sewage produced by mixing water and sludge was developed to the required concentration by diluting raw sludge with water in the 22,500-gallon reservoir. The sewage reservoir was filled with water to within about 95-percent capacity and the raw sludge was then added to the water which was kept under constant agitation to insure reasonable homogeneity of the sewage in the storage reservoir. Samples were taken from the reservoir periodically until the desired sewage concentration, based on milliliter per liter of settleable solids, was achieved.

Polymer Preparation. To facilitate handling of the polymers during testing, a slurry was first prepared in the laboratory and then used to make concentrated water/polymer solutions of 5,000 milligrams per liter in the 1,000-gallon additive storage tank. These solutions were agitated gently for approximately four hours, then samples were taken to the laboratory for viscosity tests to insure that complete hydration had occurred. An inert tracer dye was added to the solution so the additive could be observed during the testing procedure to determine the degree of mixing of additive with sewage. A detailed discussion of the technique used in mixing the polymer slurry is given in Appendix D.

Thermal Conditioning. Once the desired sewage concentration had been achieved, the sewage was adjusted to the proper temperature for testing. The cold runs at 38°F were achieved after an overnight chill of the sewage occurred by circulating the water/sewage mixture through the chiller unit of the refrigeration equipment. The second set of data was made at the ambient water temperature (approximately 70°F). Following this test, the high temperature test at 90°F was performed by heating the sewage in the same manner as the temperature reduction process with the exception that the sewage was circulated through the boiler. This sequence of testing (chill-down, ambient, heat-up) proved to be the most desirable since it



22,500 Gallon Reservoir
Pump
Magnetic Flow Meter
Gate Valve
Hersey Flowmeter
4" Line
Valve
Gage Pressure Transducer
Valve
2-way Valve
ΔP Transducer
Pressure Sensing Line
Temperature Indicator
Injection Ports
#4
#3
#2
#1
4" Line
Gate Valve
Test Fitting Section
4" Line
Effluent
Four-Inch Flow System Schematic Diagram

Figure 20. Four-Inch Flow System Schematic Diagram

allowed for maximum utilization of test time (that is, it allowed night chill-down and daytime heat-up which minimized the energy requirements for the environmental testing).

Typical Flow Testing Procedure. Throughout the flow test program, all instrumentation was periodically checked for calibration. The pressure transducers were checked with a standard water manometer, the magnetic flowmeter was checked with a positive displacement flowmeter placed in series on the line; the additive pump was checked in the same manner as the magnetic flowmeter; and the thermal sensors were checked in a constant temperature bath. Also, the slope of the sewer flow line was determined before each run. The initial polymer concentration was arbitrarily selected but subsequent concentrations were based on the calculations performed during the testing. The polymers and concentrations tested are shown in Table XIII below.

TABLE XIII

FLOW TEST POLYMER CONCENTRATIONS

Polymer	Polymer Concentration (mg/l)
AP-30	100, 250 and 500
FR-4	100, 250 and 500
D-252	100, 250 and 500
J-2FP	500 and 1,000
WSR-301	50, 100 and 200
Polyox Coagulant-701	50, 100 and 200

The six-inch sewer system's performance was determined with a slope of 0.003 for three different head conditions for each polymer at each concentration. The resulting sewage flow rates tested were 350, 450 and 550 gallons per minute. Additional testing was done at grades of 0.3 and 1.0 percent.

The volume of the 22,500-gallon reservoir was sufficient to provide flow for twelve different data collection operations. Each set of data was taken at a constant sewage concentration and sewage temperature. Three sewage flow rates and three polymer concentrations at each flow rate were tested.

Once the polymer solution and sewage were ready to be tested, flow of sewage was started by the Marlow pump and the instrumentation was zeroed. The system flow rate was then brought up to the desired value and the vernier on the polymer injection pump was set at the proper value but not actuated. The sewage flow system was then allowed to reach a steady-state condition, sewage samples were taken for analysis and the following data recorded:

Date
Ambient temperature.
Sewage reservoir temperature.
Sewage temperature at the entrance of the test section.
Sewage temperature at the exit of the test section.
Sewage flow rate.
Static pressure at sewer line entrance.
Static pressure at the entrance of the test section.
Static pressure drop across test section.
Weir box reading.

The polymer injection pump was then started at the first concentration setting, and the test section flow again was allowed to reach steady state conditions. Again, the required data was recorded and the procedure repeated (for the different polymer concentrations and sewage flow rates) until the data matrix of 12 sets was completed.

Flow Restriction Test Procedure. Of the six polymers tested in the six-inch test facility, four were selected for evaluation in the four-inch test facility, to establish the most effective injection point distance upstream for typical flow restriction characteristics. The four polymers and the concentrations tested are given in Table XIV.

TABLE XIV

RESTRICTION TEST POLYMERS

Polymer	Polymer Concentration (mg/l)
AP-30	250 and 500
FR-4	250 and 500
WSR-301	100 and 200
Polyox Coagulant-701	100 and 200

During these restriction tests, water was used rather then sewage because the data indicated minimum differences between water and sewage. Preparation of the concentrated polymer solutions was identical to that previously described.

All instrumentation was zeroed prior to each test run to prevent recording errors and to insure that all instrumentation was functioning. The test procedure for the four-inch system depended on the system configuration being tested, and whether the flow constriction resulted from deformational losses or was caused by the junction of two flows, as in the tee and wye sections.

The procedure used for the long- and short-radius elbows was as follows. The Marlow primary pump was started and the flow rate adjusted to the flow rate to be used and, after steady-state flow conditions were obtained, the following data recorded:

Water temperature in the line.
Water flow rate.
Static pressure at entrance to the blockage area.
Static pressure drop across the blockage area.
Date.
Ambient temperature.

The polymer pump vernier was set to the proper injection rate and the pump started. Injection was made at the nearest injection point (No. 1) first and the system allowed to reach steady-state prior to data recording. This first injection point was then closed, and the second injection point was opened, and the procedure was repeated for each of the other two injection points.

The procedure used for the tee and the two wyes was as follows. The Marlow primary pump was again started with the valves in the two upstream lines in the full open position. Once the flow system reached steady-state, the following data was recorded:

Water temperature in the line.
System total flow rate.
Water flow rate in the non-injection line.
Static pressure at entrance to turned flow portion of the blockage area.
Static pressure drop across the straight flow portion of the blockage area.
Static pressure drop across the turned flow portion of the blockage area.
Ambient temperature.

The same injection procedure and data acquisition was then followed as described for the elbows. The injection system was then taken off line and the flow was redistributed through the two legs of the primary flow system in the lines. The above procedure was repeated until eight different flow distributions had been achieved.

Chemical and Physical Characteristics of Polymer-Sewage System

During the tests in which selected polymers were injected into the six-inch test conduit, statistical sampling was conducted on the sewage and polymer-sewage combinations (for WSR-301 and Polyox Coagulant-701) to determine any affects of the polymers on sewage, and to record the specific characteristics of the material used in the flow data collection.

By its very nature, raw sewage cannot be considered homogeneous; however, in the project tests, parameter values were controlled as well as possible so that comparative values could be established within the data. The test parameters were established from various sewage treatment plant records in the Dallas, Texas, area (Table XV).

TABLE XV

RAW SEWAGE CHARACTERISTICS OF DALLAS, TEXAS AREA

Total solids, mg/l	1,370
Dissolved solids, mg/l	1,010
Suspended solids, mg/l	360
Total volatile solids, mg/l	780
Total non-volatile solids, mg/l	591
pH	6.5
Chlorides, mg/l	333
DO, mg/l	1.0
BOD, mg/l	212
Sulfates, mg/l	161
Total sulfides, mg/l	2.7
H_2S, mg/l	1.2
Ammonia nitrogen, mg/l	0.4
Temperature, °F	75

Tests conducted on sewage or polymer and sewage were conducted in accordance with procedures outlined in Standard Methods for Examination of Water and Wastewater with measured parameters, including settleable solids, total solids, dissolved solids, suspended solids, pH, chlorides, hardness, chemical oxygen demand (COD), dissolved oxygen, specific conductance, oil and grease, and temperature.

The control factor accurately maintained in diluting raw, concentrated sewage, to the levels generally found in combined municipal sewage, was settleable solids. Recorded data of these tests as they relate to the flow testing with various polymers and polymer concentrations are found in Table XVI.

The values of chlorides and calcium-carbonate hardness follow a narrow consistent range of values (Table XVI) as expected, since these parameters are primarily derived from the water in the sewage. These factors do not contribute to or deter the function of the polymers as friction reducers in overflowing sewer lines.

Values obtained from the tests, which depend upon the electrolytic nature of the sewage and the polymers (i.e., pH and specific conductance), vary erratically with increased polymer concentration; however, the maximum variation in pH was 0.69 and the maximum variation in specific conductance was 32.4 micro-mhos per cubic centimeter.

The tendency for the values of the total solids and dissolved solids to increase with an increase in polymer concentration was expected because of the gross quantity of polymer injected.

The suspended solid values of the sewage were reduced when polymers were injected into the model sewer line, with the greatest reduction obtained with the lower polymer concentration (50 milligrams per liter). The suspended solids are dependent upon the total solids and the dissolved solids; therefore, as the polymer solids concentration increased, the reduction in suspended solids generally decreased proportionately.

Erratic values were found during the oil and grease testing and probably occurred because the material tended to coalesce or lump. The data showed no change with change in polymer concentration.

The COD values increased with increases in the polymer concentration. The test indicated the amount of carbonaceous or organic material available for oxidation by a strong chemical oxidant. Thus the analysis should show increased COD due to inclusion of the polymers (an organic material) which are, although, a minor part of the immediate biochemical load upon the oxygen assets of the sewage receiving the polymer injection.

An increase in COD was, in fact, measured in the polymer-sewage mixture as the polymer concentration was increased. This increase in COD can be seen by the tabulations shown in Table XVI.

In a typical sewer system, the polymer concentration injected should be greatly diluted when the flow from a surcharged section of the collection system merges with the downstream flow from other sections of the collection system. For example, in one sewer system investigated during rainy weather, the flow in the restricted section was 9.4 million gallons per day (mgd). Since the total downstream flow in the system was estimated at 40 mgd, the polymer concentration used should be diluted by a factor of four; however, if the polymer injected in a collection system to reduce the energy required to overcome friction losses should result in any concentration at the treatment plant, it should be less than those normally used for coagulation. Thus, the organic load of the effluent of the treatment plant should not be materially, if at all, affected by the polymers injected into the collection system.

The dissolved oxygen (DO) values showed definite relationship to the amount of agitation occurring in the storage reservoir during testing, and to the temperature of the sewage; however, no correlation pattern developed between the DO parameter and the polymer injection concentration. There was some tendency for DO values to be slightly higher at low temperatures than at higher temperatures, due to the better oxygen-retention capability of water at lower temperatures.

Most of the test data obtained from measuring the various characteristics showed that there was little affect of the polymers injected upon the sewage and, for practical purposes, all polymers injected at various concentrations remained available for friction reduction.

TABLE XVI

PHYSICAL AND CHEMICAL CHARACTERISTICS OF POLYMER-SEWAGE SYSTEMS

Polymer	Polymer Conc. (mg/l)	Settleable Solids (ml/l)	Total Solids (mg/l)	Dissolved Solids (mg/l)	Suspended Solids (mg/l)	pH	Chlorides (mg/l)	Hardness $CaCO_3$ (mg/l)	COD (mg/l)	DO (mg/l)	Specific Cond. (μmhos/cm)	Oil & Grease (mg/l)	Temp. (°F)
301	0	9	202	187	15	7.8	32	70	47	5.2	249.8	60.0	90
301	50	9	278	266	12	8.0	31	71	407	1.7	259.3	64.8	90
301	100	9	304	283	21	8.1	31	71	634	1.7	282.2	36.0	90
301	200	9	402	350	52	8.2	32	68	944	1.5	270.3	78.0	90
301	0	9	473	197	240	8.5	31	82	293	7.0	268.0	24.4	74
301	50	9	295	257	38	8.4	30	78	432	6.0	246.0	128.8	74
301	100	9	360	291	69	8.4	30	77	624	7.0	247.9	124.2	74
301	200	9	415	362	53	8.4	31	79	924	7.3	247.9	42.1	74
301	0	9	323	195	148	8.3	30	78	215	8.8	209.5	0.0	38
301	50	9	322	260	62	8.4	31	76	432	7.5	204.6	3.2	38
301	100	9	374	300	74	8.4	31	76	636	7.1	208.1	4.4	38
301	200	9	456	353	203	8.4	31	76	909	7.9	214.1	2.8	38
701	0	9	266	179	87	7.4	30	78	52	5.4	271.8	2.4	90
701	50	9	285	233	52	7.6	30	82	304	4.4	275.7	5.6	90
701	100	9	321	250	71	7.6	29	80	486	4.2	303.6	15.3	90
701	200	9	383	303	80	7.6	30	80	757	4.2	279.7	1.2	90
701	0	9	425	185	240	7.4	30	80	220	7.7	239.3	10.8	75
701	50	9	282	222	60	7.9	29	76	317	6.9	264.3	1.2	75
701	100	9	326	264	62	7.8	30	78	544	7.2	271.8	17.2	75
701	200	9	389	320	69	7.5	30	78	868	7.0	271.0	6.0	75
701	0	9	248	180	68	7.5	30	76	23	9.3	209.0	13.2	39
701	50	9	284	227	57	8.1	30	76	312	6.9	199.9	19.6	39
701	100	9	323	268	55	8.1	31	78	500	6.9	200.7	4.8	39
701	200	9	378	329	49	8.0	30	78	790	8.9	209.0	19.2	39
301	0	3	309	180	129	7.2	31	78	168	6.7	236.2	37.2	90
301	50	3	266	210	56	7.3	29	78	305	6.3	232.3	9.2	90
301	100	3	304	236	68	7.3	30	78	505	6.1	234.6	17.2	90
301	200	3	364	267	97	7.3	30	80	809	5.6	227.9	4253.2	90
301	0	3	424	190	234	7.2	31	86	315	7.3	234.6	414.4	75
301	50	3	291	210	81	7.3	30	76	339	4.5	238.1	6.0	75
301	100	3	335	234	101	7.3	30	76	532	4.1	261.4	80.0	75
301	200	3	405	269	136	7.3	30	76	860	3.1	259.3	19.2	75
301	0	3	446	186	260	7.5	31	86	380	7.7	207.7	41.6	38
301	50	3	331	204	127	7.7	31	76	346	6.0	217.1	530.8	38
301	100	3	366	233	133	7.7	30	80	515	6.2	217.1	0.0	38
301	200	3	434	277	157	7.7	30	80	827	5.7	221.6	413.3	38
701	0	3	286	184	102	7.3	32	76	55	7.0	245.4	47.5	90
701	50	3	261	248	13	7.4	31	76	320	5.2	235.7	550.4	90
701	100	3	286	264	22	7.4	31	80	457	5.1	251.8	18.0	90
701	200	3	332	304	28	7.3	31	80	718	5.9	252.5	78.0	90
701	0	3	307	195	112	7.4	32	78	109	4.3	233.4	13.2	74
701	50	3	272	206	66	7.4	32	80	287	3.2	255.2	16.4	74
701	100	3	302	270	32	7.4	32	80	428	3.1	251.2	10.4	74
701	200	3	367	318	49	7.4	32	80	734	1.5	251.8	419.2	74
701	0	3	208	195	13	8.3	33	78	26	9.2	220.6	10.8	38
701	50	3	259	250	9	8.5	33	78	332	7.4	225.8	2.8	38
701	100	3	301	288	12	8.5	33	76	519	7.5	229.5	43.2	38
701	200	3	339	329	10	8.5	33	80	730	7.5	216.6	40.0	38

Six-Inch Flow System Test Results

The results of the six-inch test sewer screening were obtained by evaluating (under the controlled conditions described in Table XVII) five of the six selected polymers. One polymer candidate, J-2FP, was not tested in the matrix because of its ineffectiveness as a friction reducer. The test results presented were established as a function of the non-polymered sewage flow rate, sewage characteristic, pressure loss, temperature, and polymer concentration.

The matrix of test data taken on the six-inch test facility is shown in Table XVII. Several data points were run repeatedly to insure repeatability of the data.

TABLE XVII

MATRIX OF FLOW DATA USED

Polymer	Polymer Concentration (mg/1)	Temperature (°F)	Sewage Settleable Solids (ml/1)
AP-30	100, 250 and 500	38	0
	100, 250, 350 and 500	70	0
	100, 250, and 500	90	0
FR-4	100, 250, and 500	38	0
	100, 250, and 500	71	0
	100, 250, and 500	90	0
D252	100, 250, and 500	38	0
	100, 250, and 500	70	0
	100, 250, and 500	90	0
WSR-301	50, 100, and 200	38	0
	50, 100, and 200	70	0
	50, 100, and 200	90	0
	50, 100, and 200	38	3
	50, 100, and 200	74	3
	50, 100, and 200	90	3
	50, 100, and 200	38	9
	50, 100, and 200	74	9
	50, 100, and 200	90	9
Polyox Coagulant-701	50, 100, and 200	38	0
	50, 100, and 200	73	0
	50, 100, and 200	90	0
	50, 100, and 200	38	3
	50, 100, and 200	74	3
	50, 100, and 200	90	3
	50, 100, and 200	38	9
	50, 100, and 200	74	9
	50, 100, and 200	90	9

The results of the six-inch sewer section screening tests are presented graphically in Figures 21 through 53. Examples and an explanation of how the graphs were derived from actual test data are given in Appendix C.

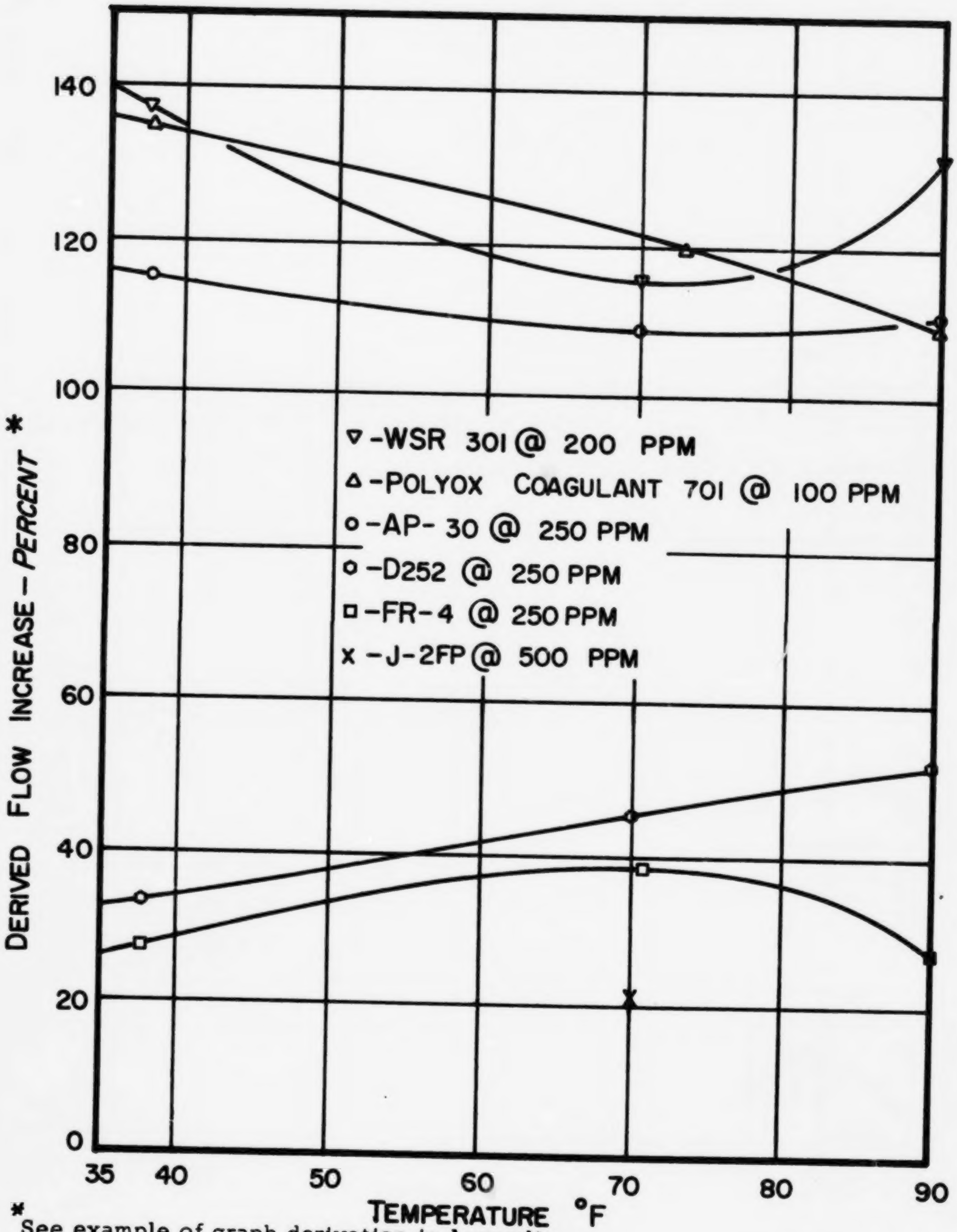
Initially the behavior of the polymers in the six-inch system was observed in water containing no sewage. These tests were performed at various flow rates, polymer concentrations, and temperatures. For the purpose of comparison, a flow rate of 300 gallons per minute was chosen to evaluate the increase in flow rate at constant head pressure. The calculations of increased flow rate with polymer, as shown in Figures 21 through 53, was accomplished by using flow curves (flow rate versus friction pressure loss) to determine the friction head loss for sewage at 300 gallons per minute. At this head loss, flow rates for sewage with each of three polymer concentrations (50 ppm, 100 ppm, and 200 ppm) were determined, and the percent flow increase calculated as

$$\frac{\text{Flow with polymer - 300 gpm}}{\text{300 gpm}} \quad (100)$$

The polymers selected for testing, did not produce high friction pressure losses as occurred for sewage without polymer. Therefore, it was necessary to extrapolate the flow rate that would have occurred for the sewage/polymer mixture. Specific concentrations were then chosen for each polymer based on its cost and the amount of additive required. Based on the selected polymer concentrations, the results of this analysis indicated that, over a temperature range of 38°F to 90°F, the polymers ranked in the following order with respect to flow increase at constant head 1) Polyox Coagulant-701, 2) WSR-301, 3) AP-30, 4) D-252, 5) FR-4, and 6) J-2FP. Concentrations, temperatures and derived flow increases are shown in Figure 21.

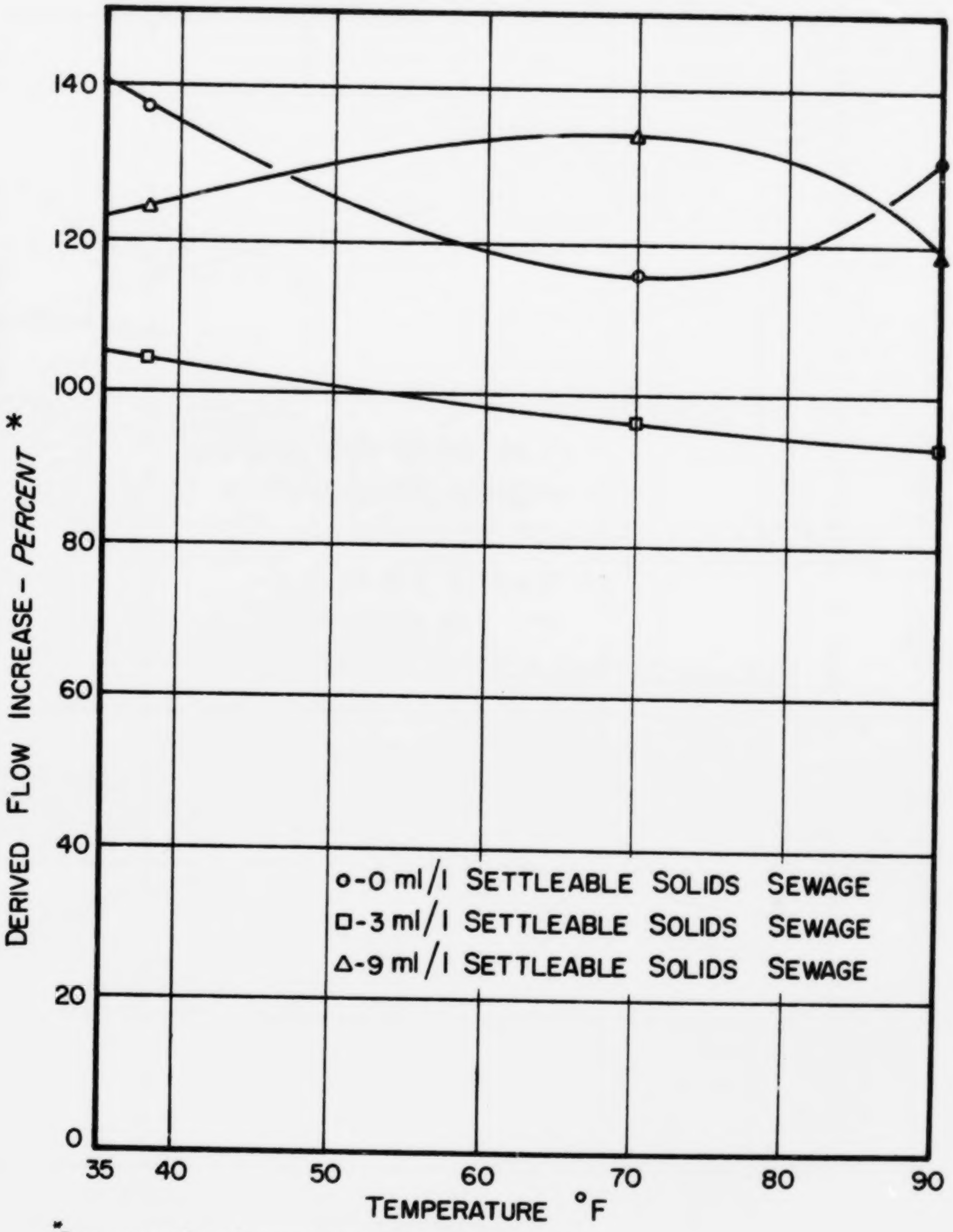
Because of the relatively high concentrations required to achieve flow increases comparable with the other polymers, J-2FP was not scheduled for further testing after the ambient temperature run. This polymer additive was the least expensive of the six additives tested, but its lower cost was not sufficient to overcome the disadvantages of having to use larger injection equipment and larger quantities of the polymer.

Although D-252 ranked fourth in the rating, it was not chosen for further consideration due to the difficulty of on-site injection, as explained in Section III. The process involved would require batch mixing and thus, would require more complicated and costly injection equipment. Since this was the only major disadvantage associated with the additive, a complete test data matrix was performed. It is believed that, under certain circumstances, D-252 could prove to be a contender. One such case might be where the sewage or sludge is pumped over long distances in forced mains resulting in high fluid shear rates in the line.



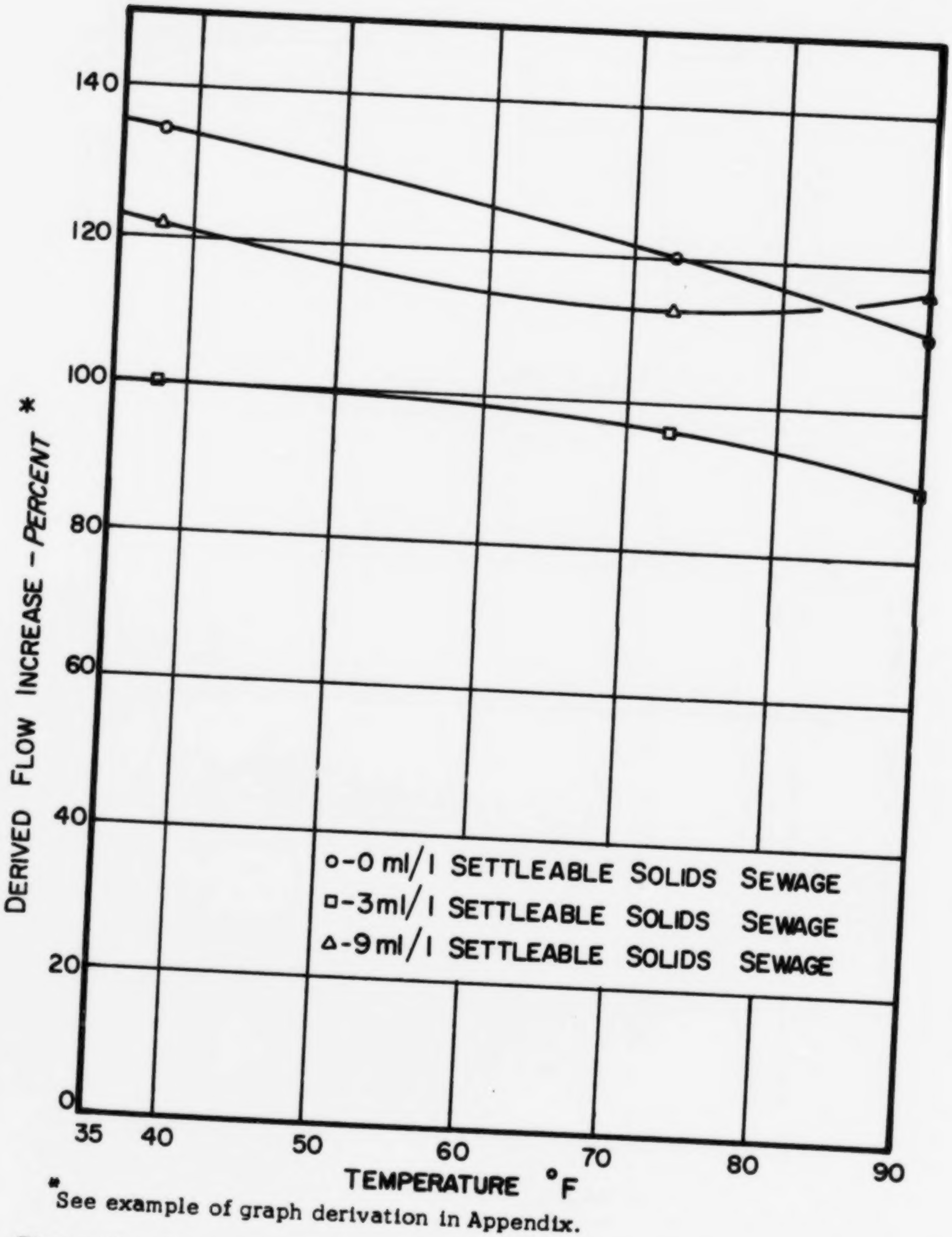
*See example of graph derivation in Appendix.

Figure 21. Comparison of the Effectiveness of Six Additives in Water as a Function of Temperature.



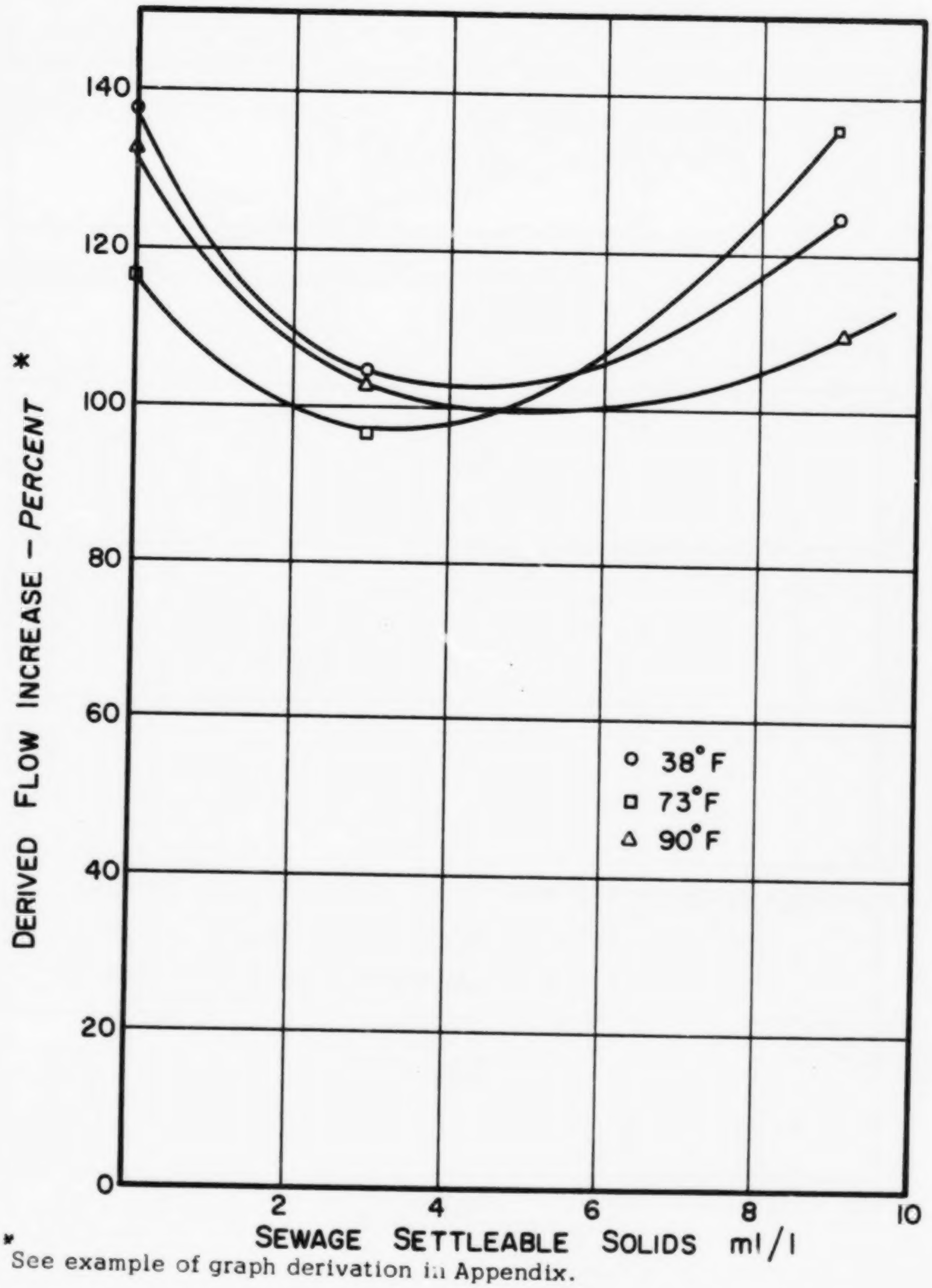
*See example of graph derivation in Appendix.

Figure 22. Comparison of the Effectiveness of WSR-301 at 200 mg/l in Sewage as a Function of Temperature.



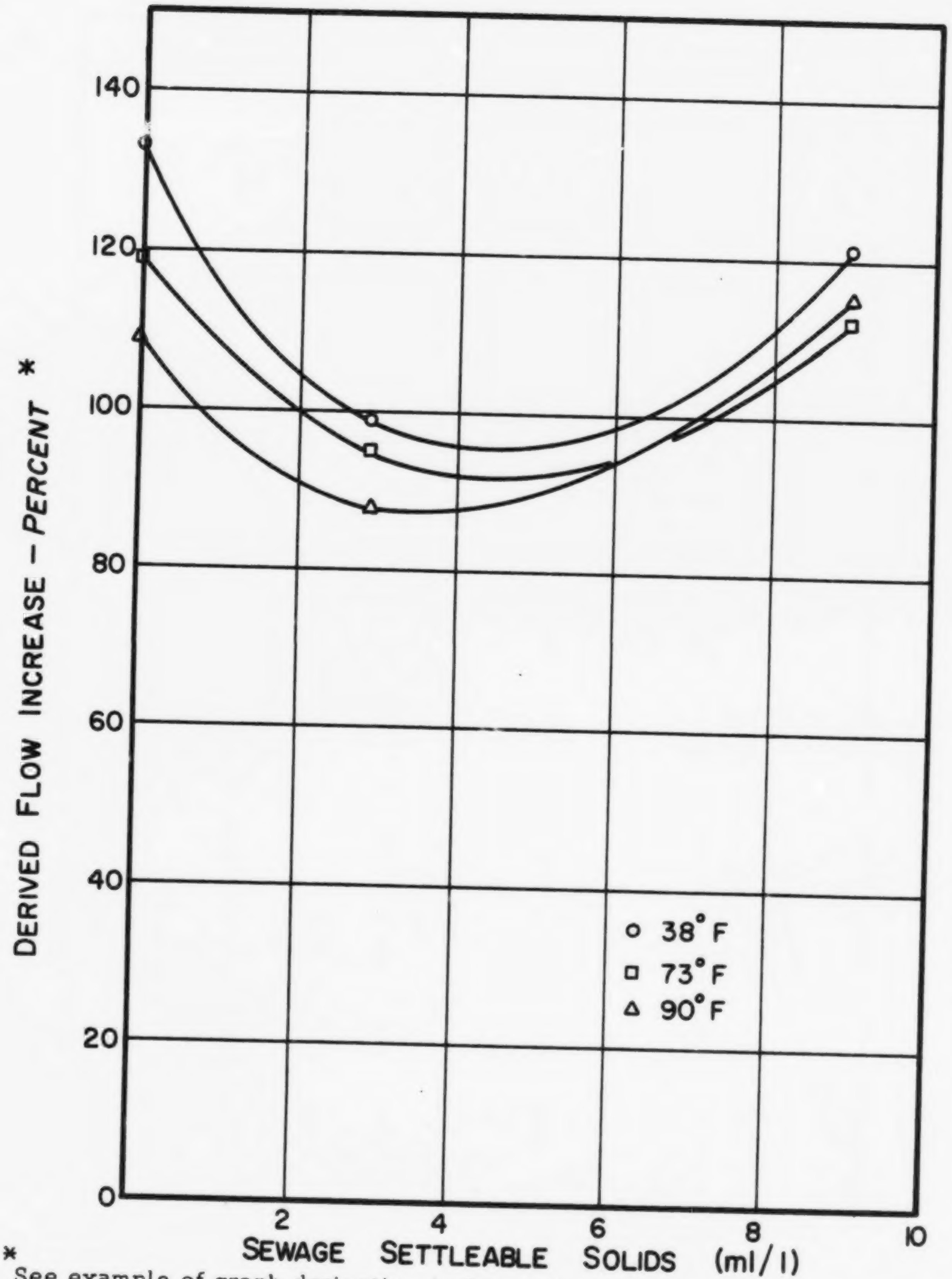
*See example of graph derivation in Appendix.

Figure 23. Comparison of the Effectiveness of Polyox Coagulant-701 at 100 mg/l in Sewage as a Function of Temperature.



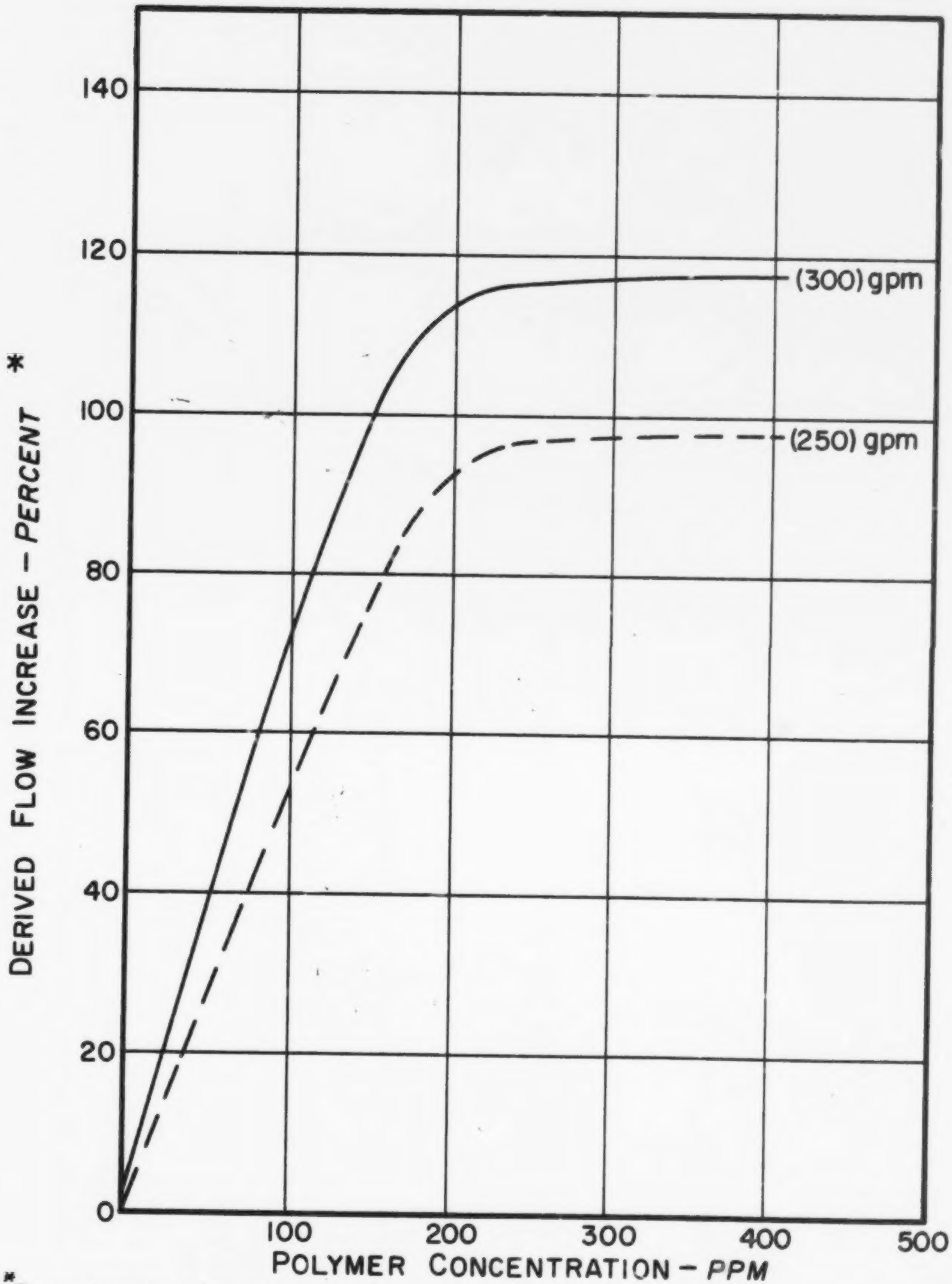
*See example of graph derivation in Appendix.

Figure 24. WSR-301 at 200 mg/l in Sewage at Indicated Temperatures, Six-Inch Test Facility.



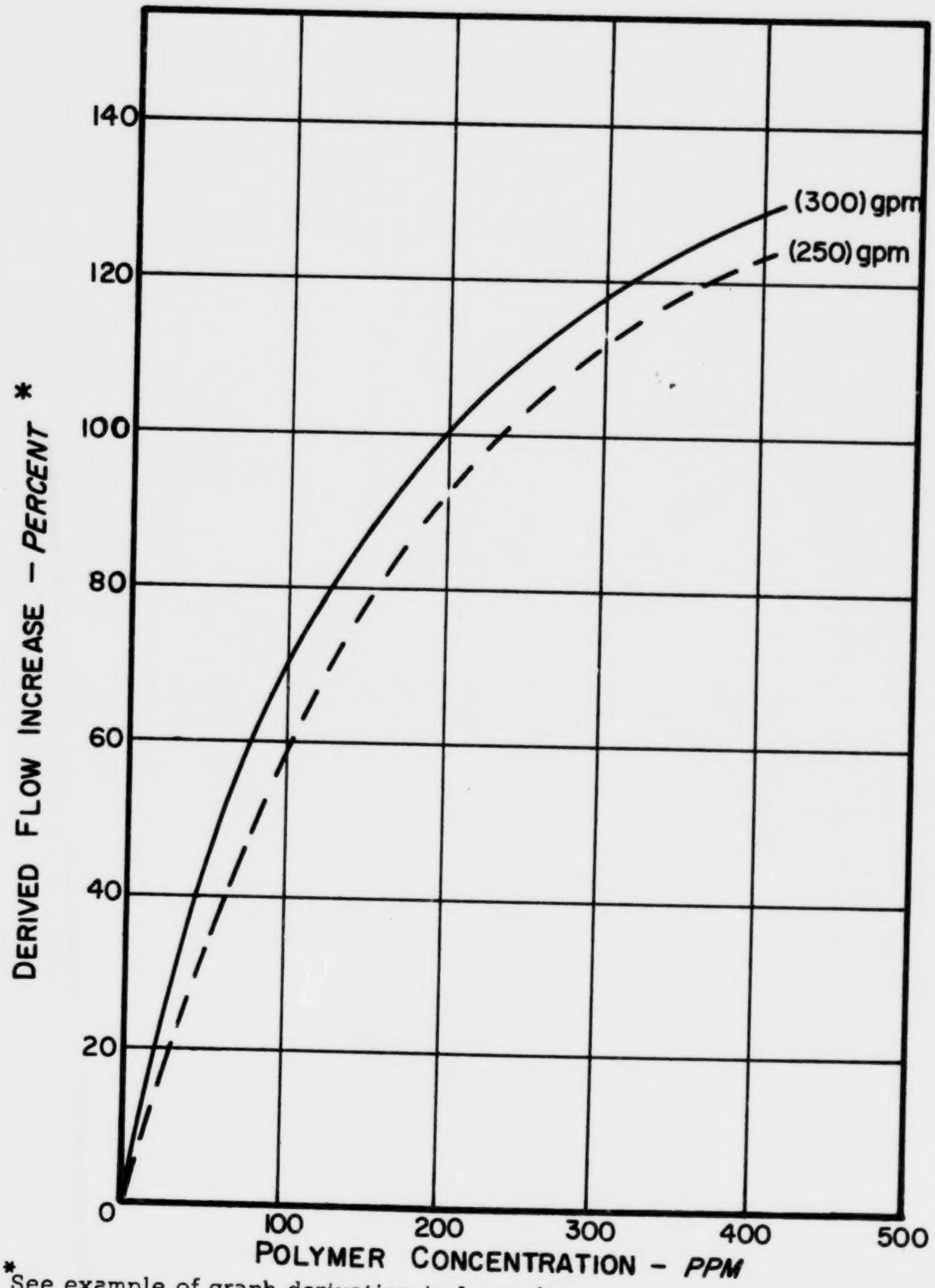
*See example of graph derivation in Appendix.

Figure 25. Polyox Coagulant-701 at 100 mg/l in Sewage at Indicated Temperatures.



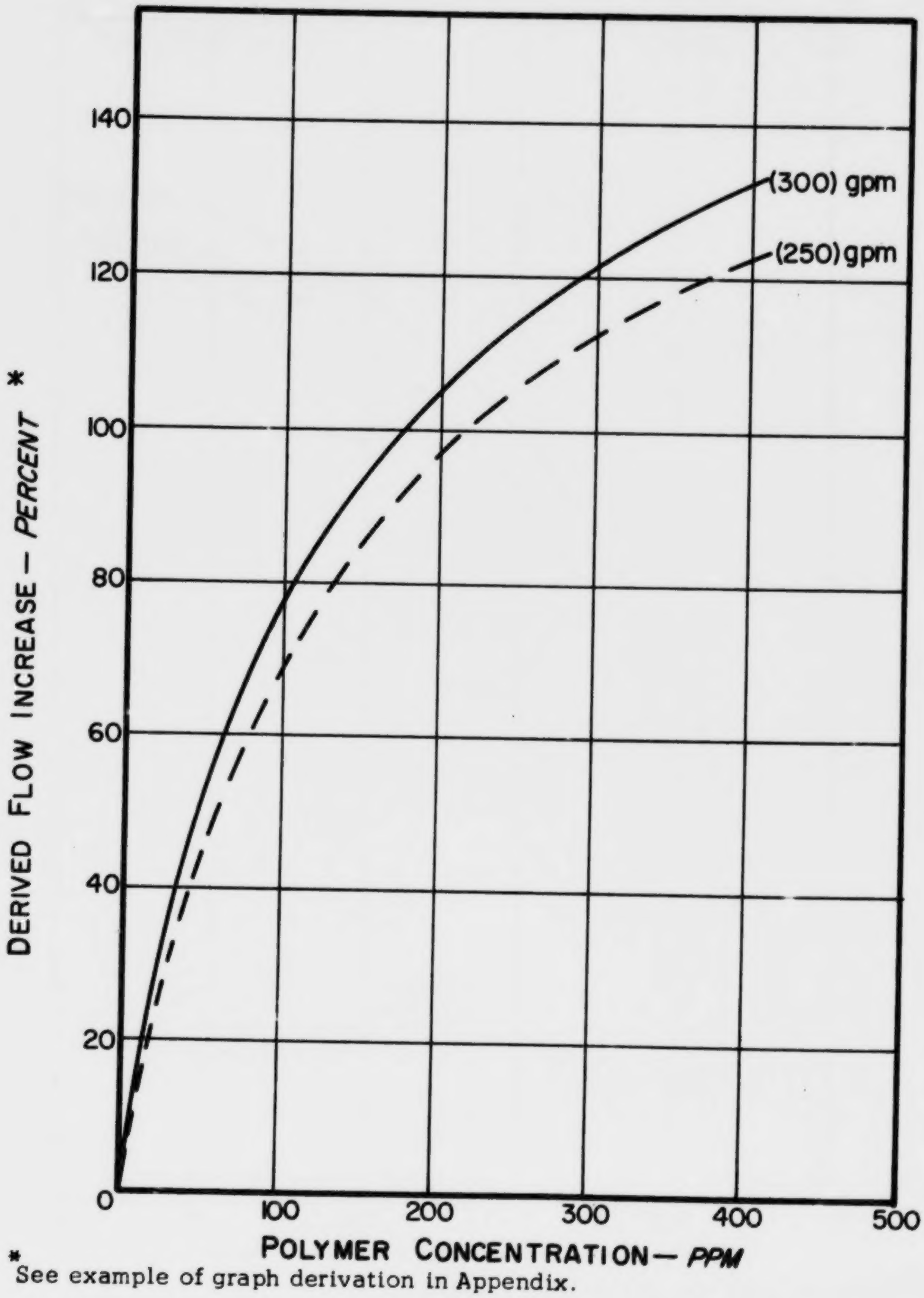
*See example of graph derivation in Appendix.

Figure 26. AP-30 in Six-Inch Test Facility at 38°F.



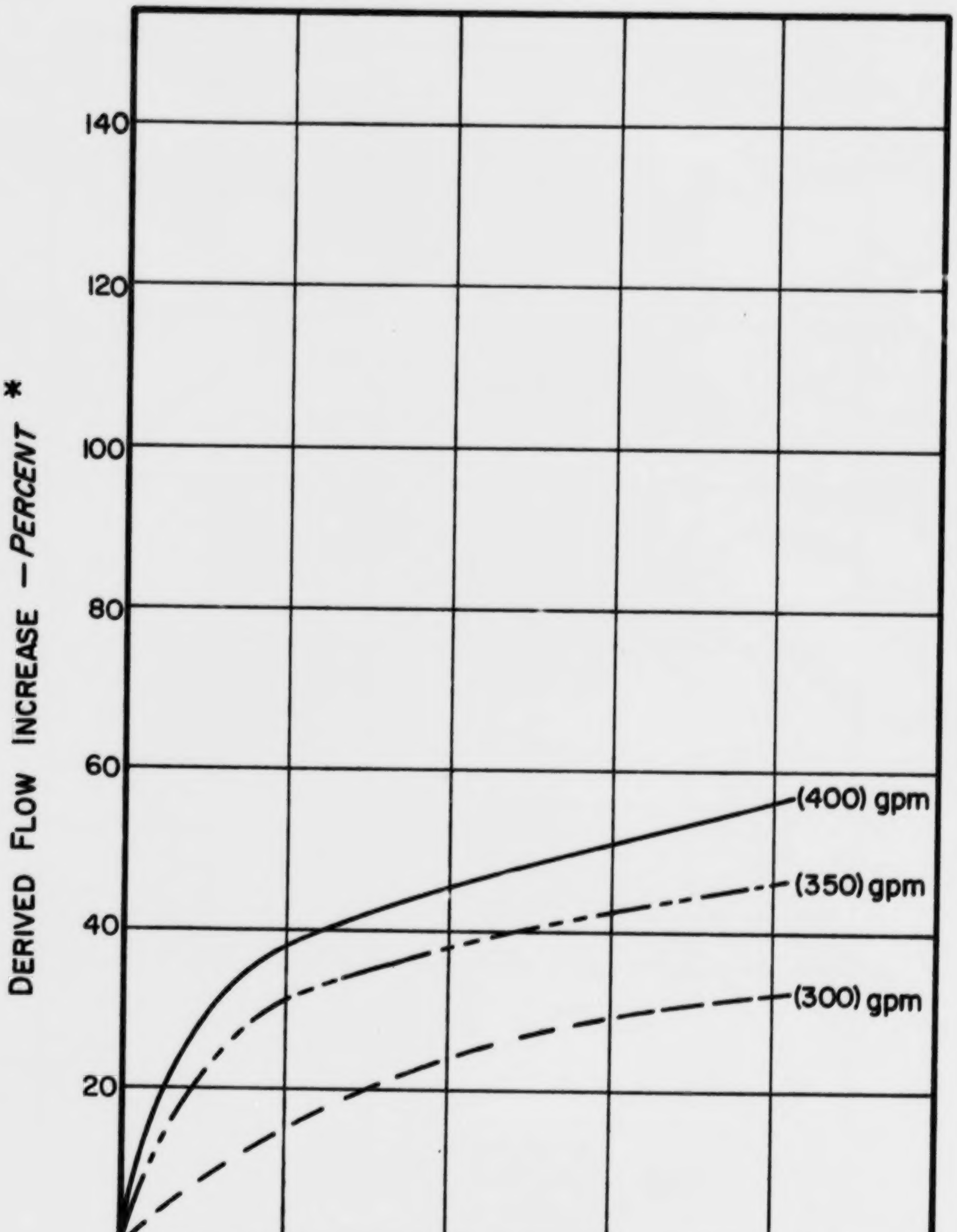
*See example of graph derivation in Appendix.

Figure 27. AP-30 in Six-Inch Test Facility at 70°F.



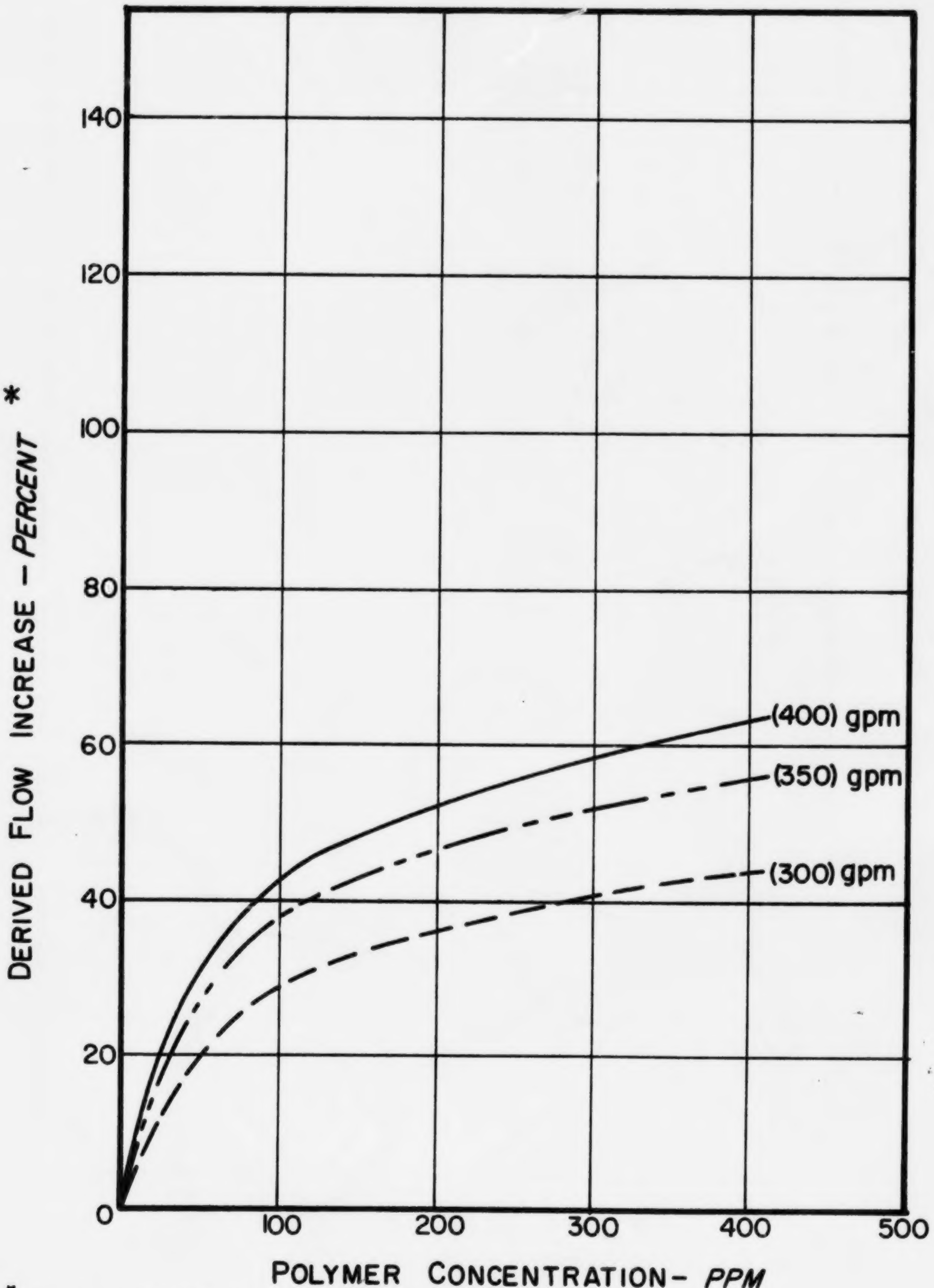
* See example of graph derivation in Appendix.

Figure 28. AP-30 in Six-Inch Test Facility at 90°F.



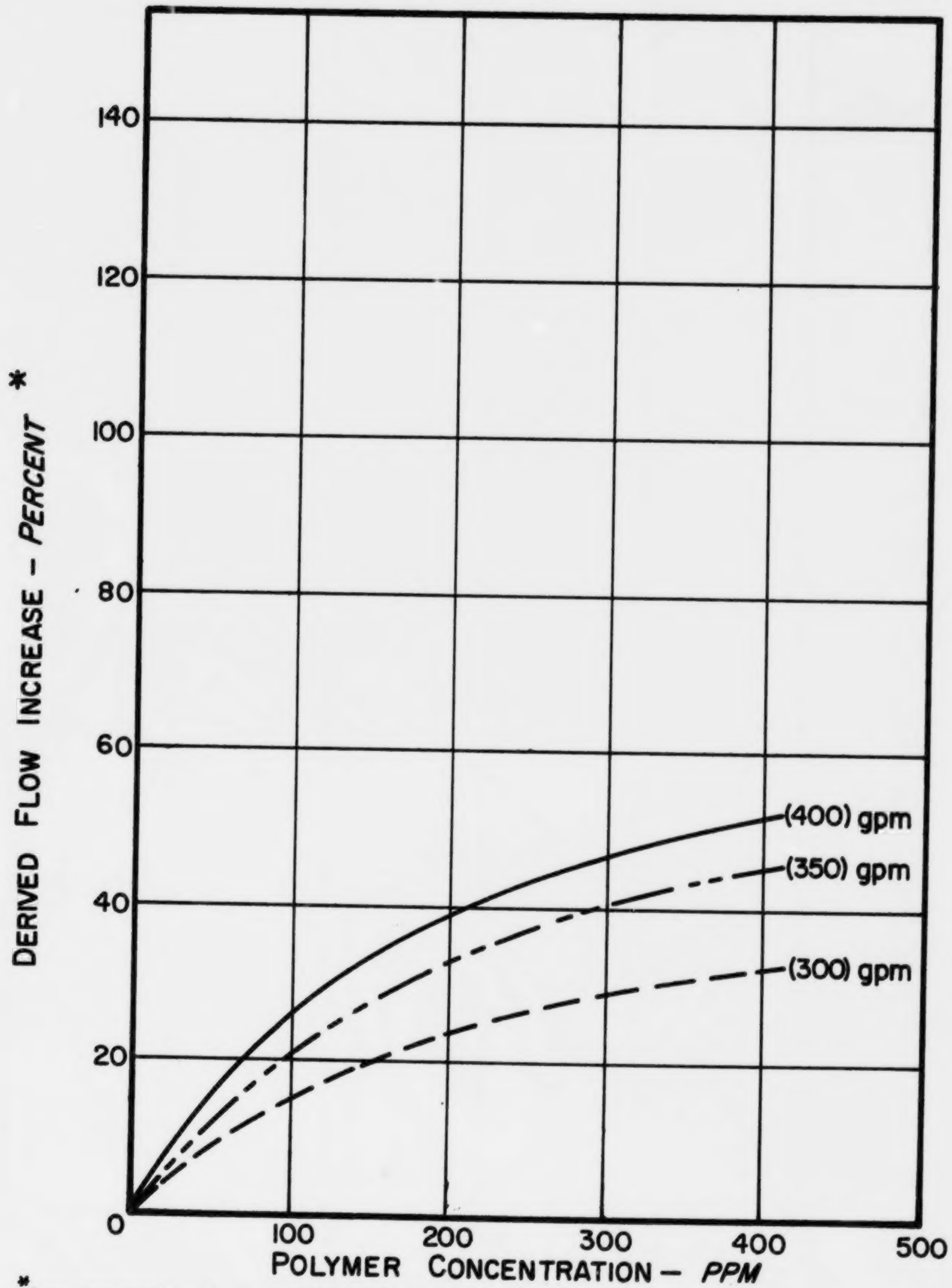
*See example of graph derivation in Appendix.

Figure 29. FR-4 in Six-Inch Test Facility at 38°F.



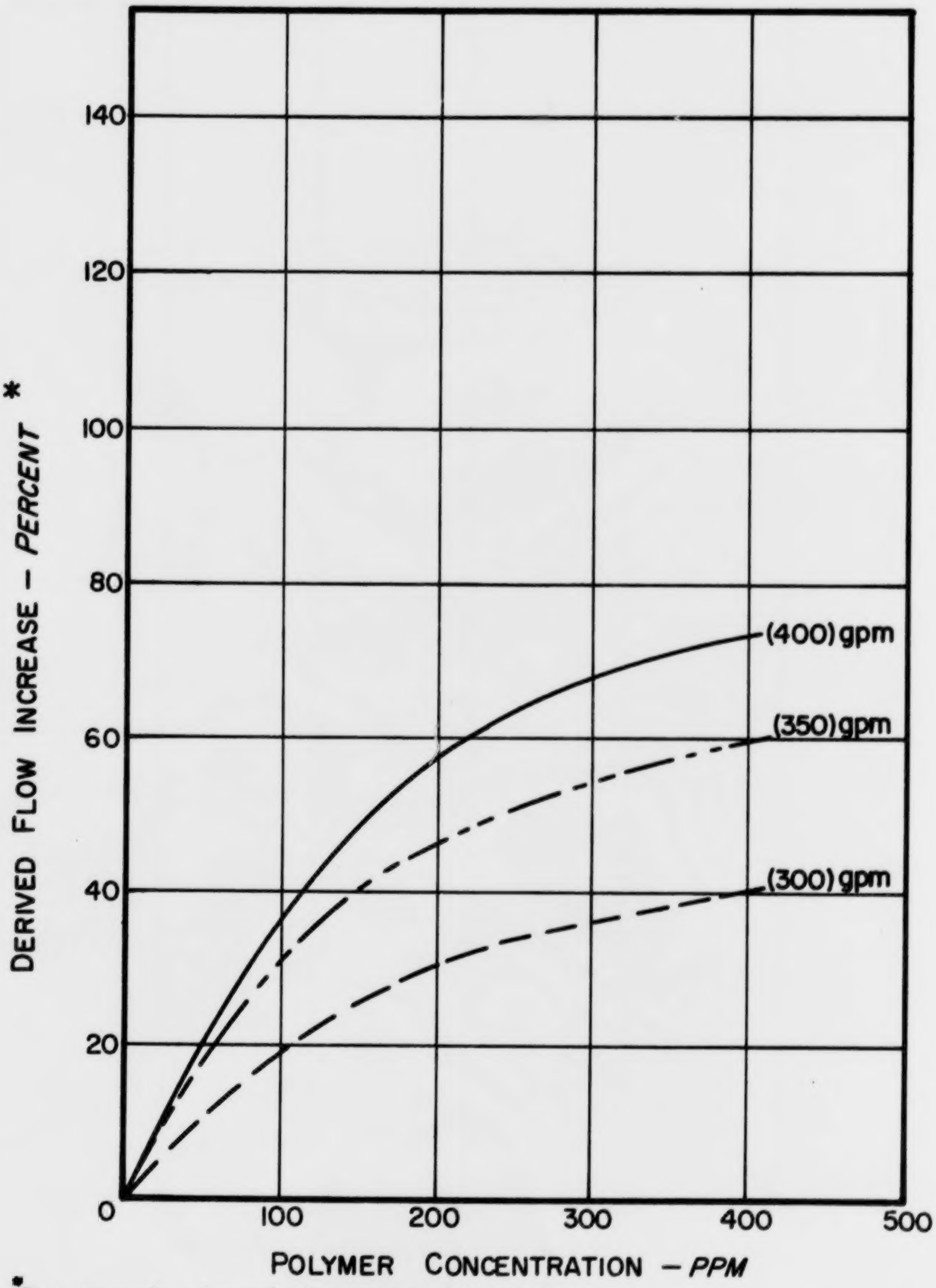
*See example of graph derivation in Appendix.

Figure 30. FR-4 in Six-Inch Test Facility at 71°F.



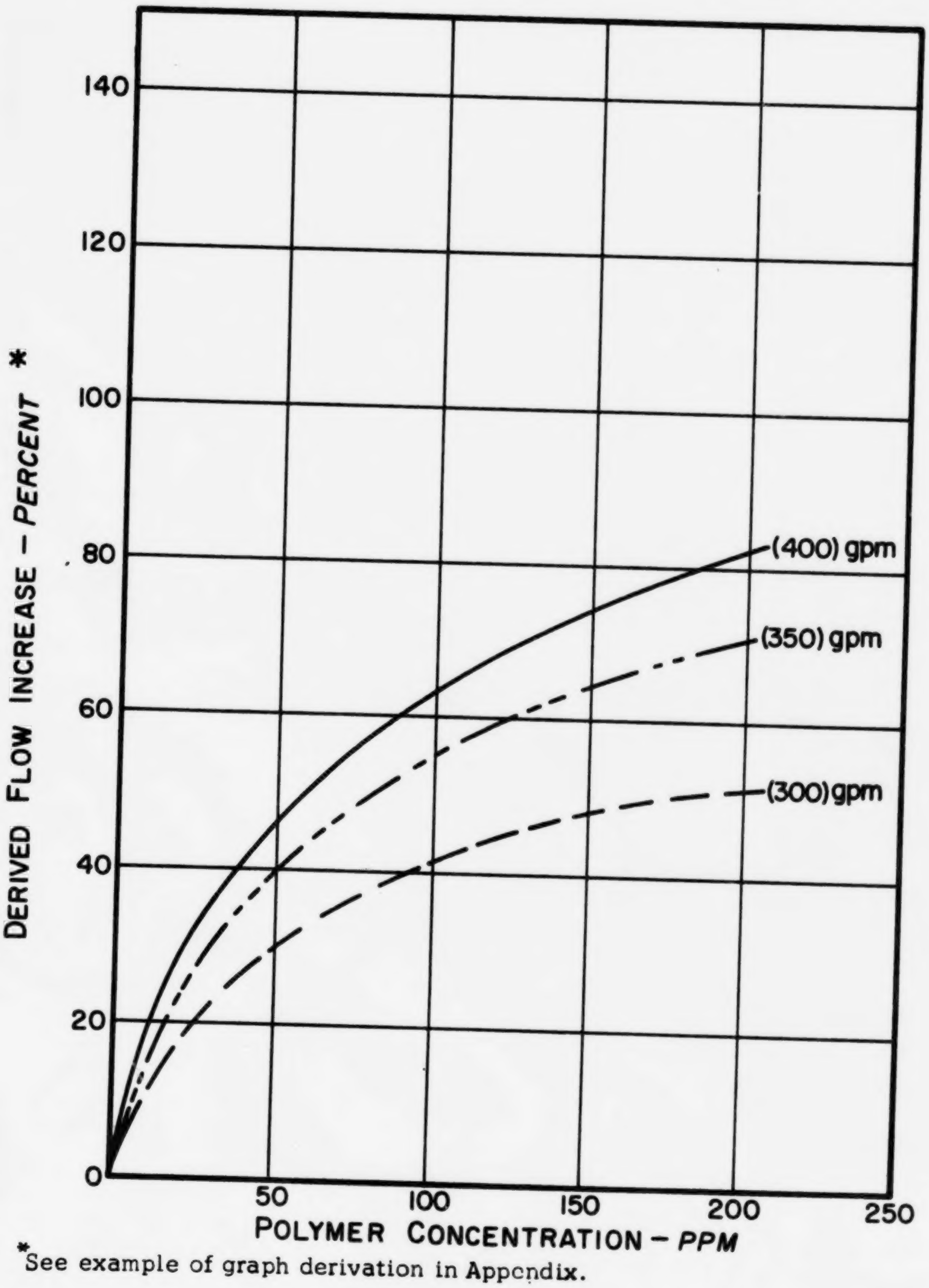
*See example of graph derivation in Appendix.

Figure 31. FR-4 in Six-Inch Test Facility at 90°F.



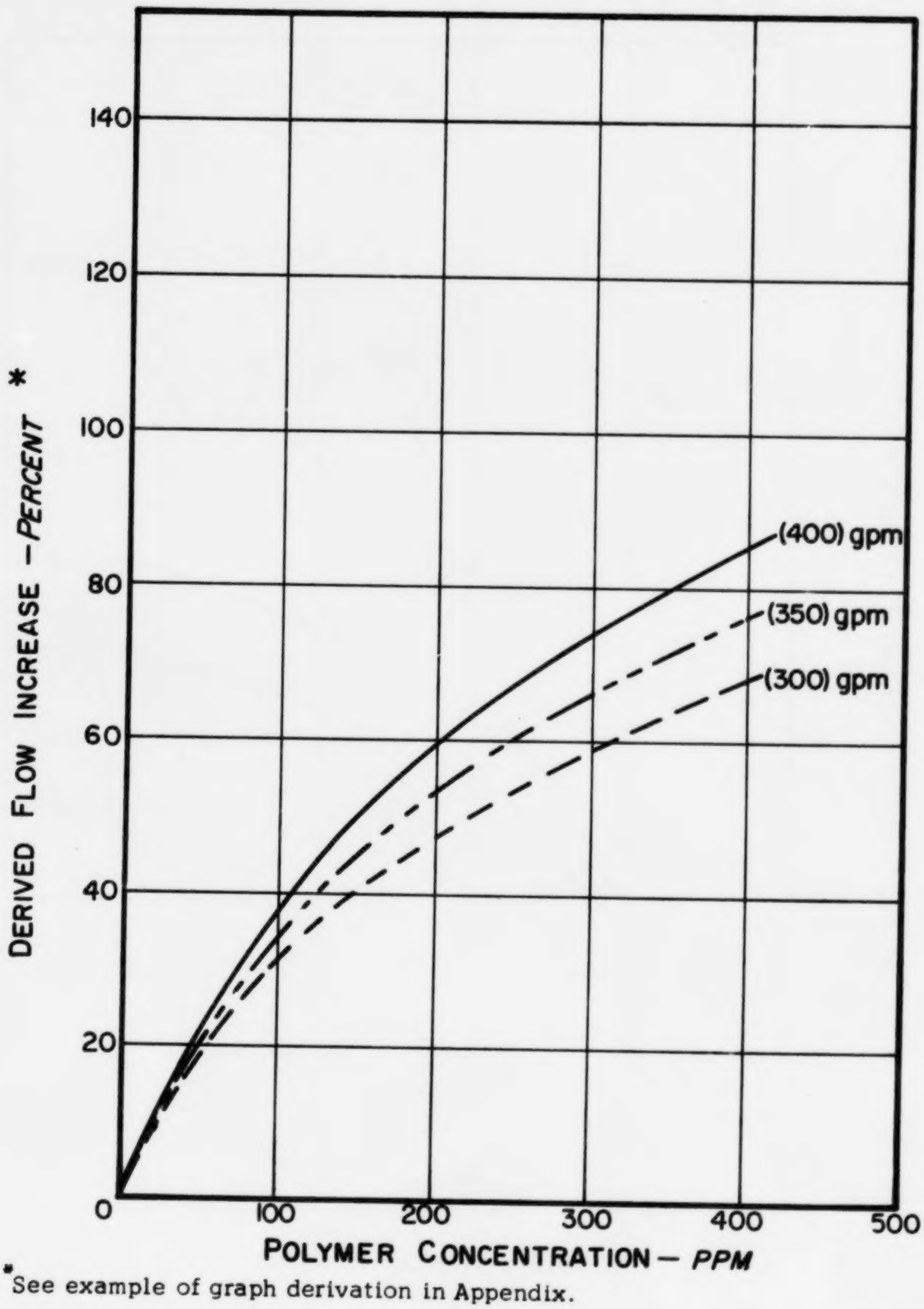
*See example of graph derivation in Appendix.

Figure 32. D-252 in Six-Inch Test Facility at 38°F.



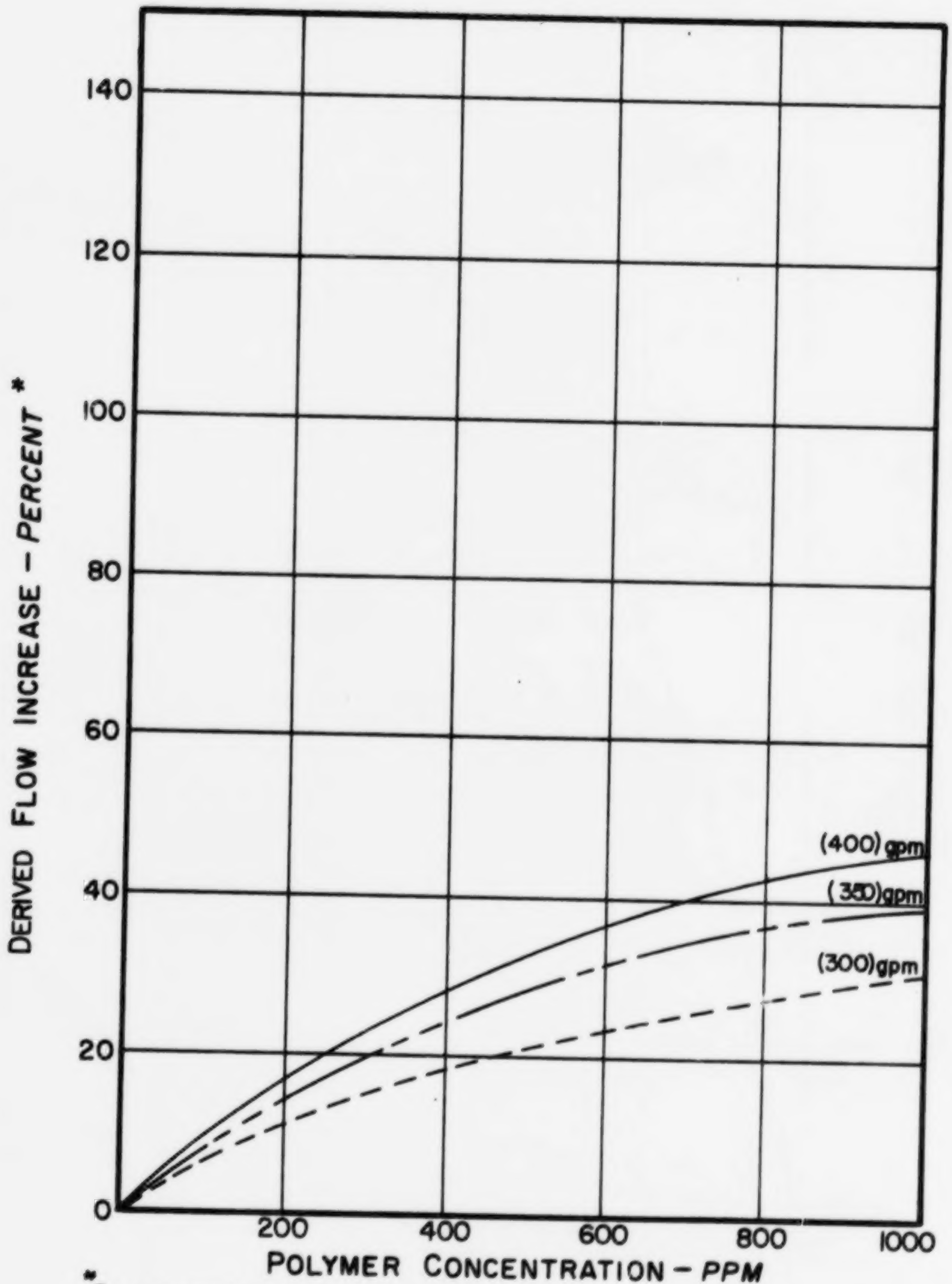
*See example of graph derivation in Appendix.

Figure 33. D-252 in Six-Inch Test Facility at 70°F.



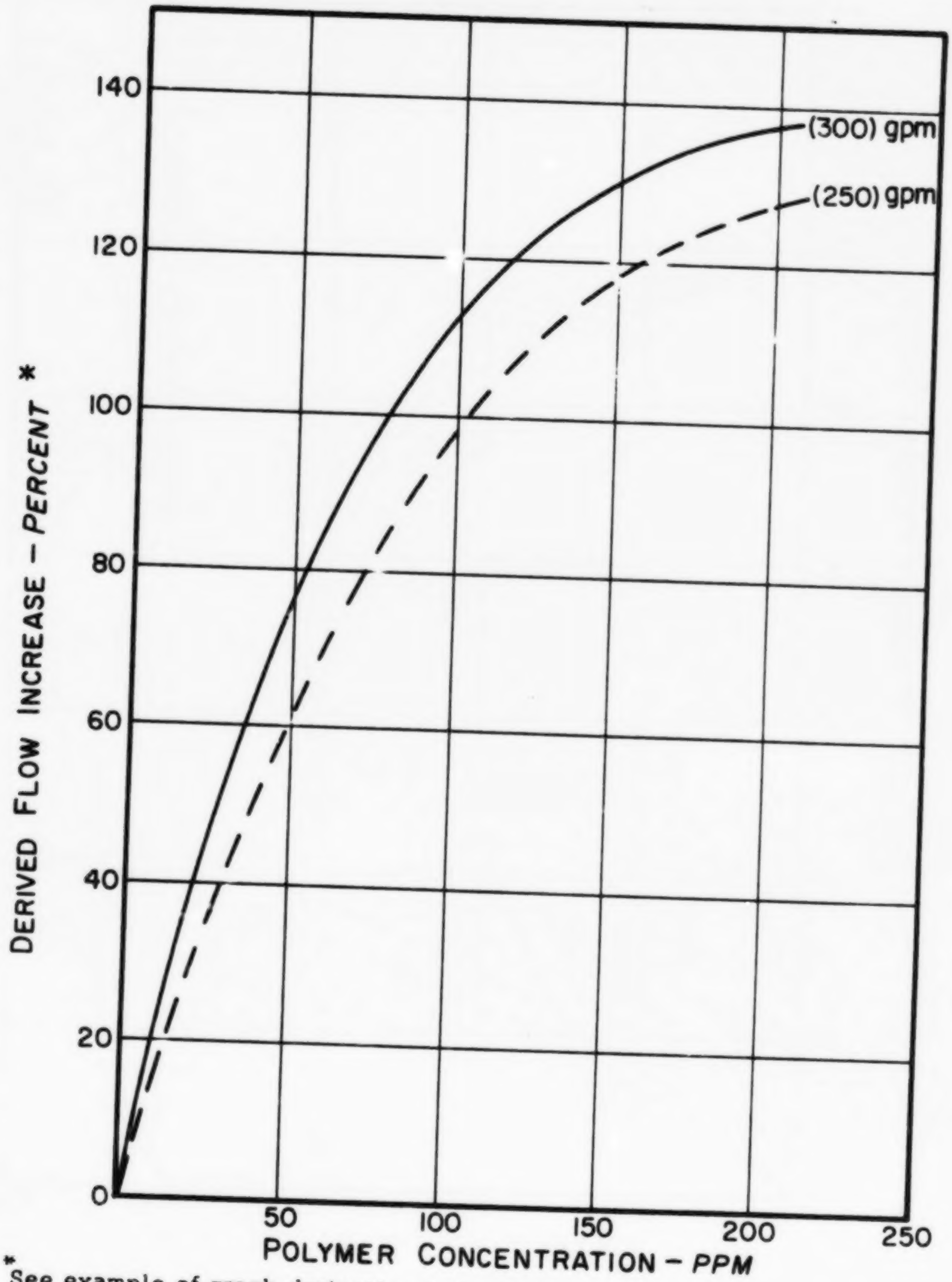
*See example of graph derivation in Appendix.

Figure 34. D-252 in Six-Inch Test Facility at 90°F.



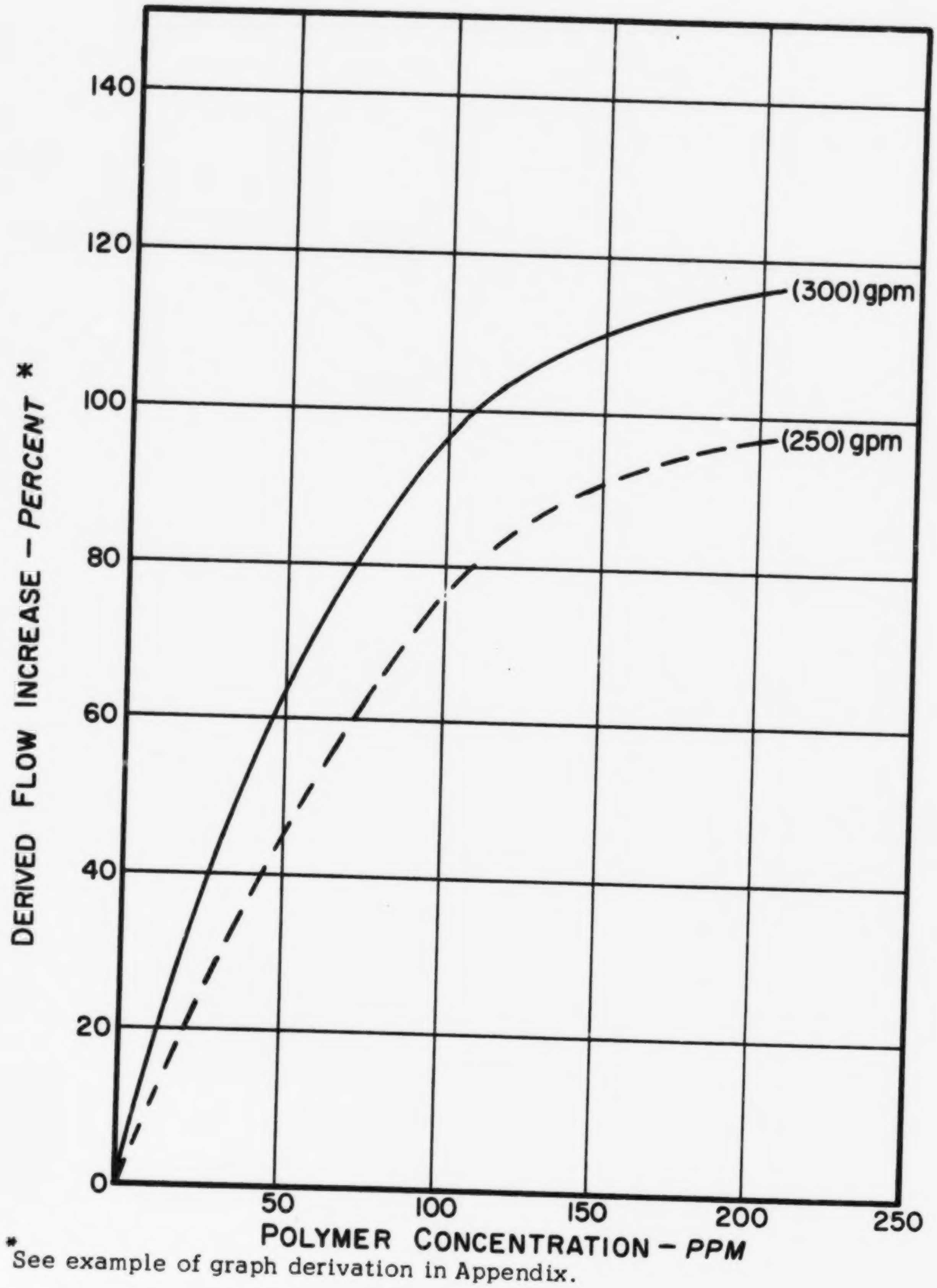
*See example of graph derivation in Appendix.

Figure 35. J-2FP in Six-Inch Test Facility at 72°F



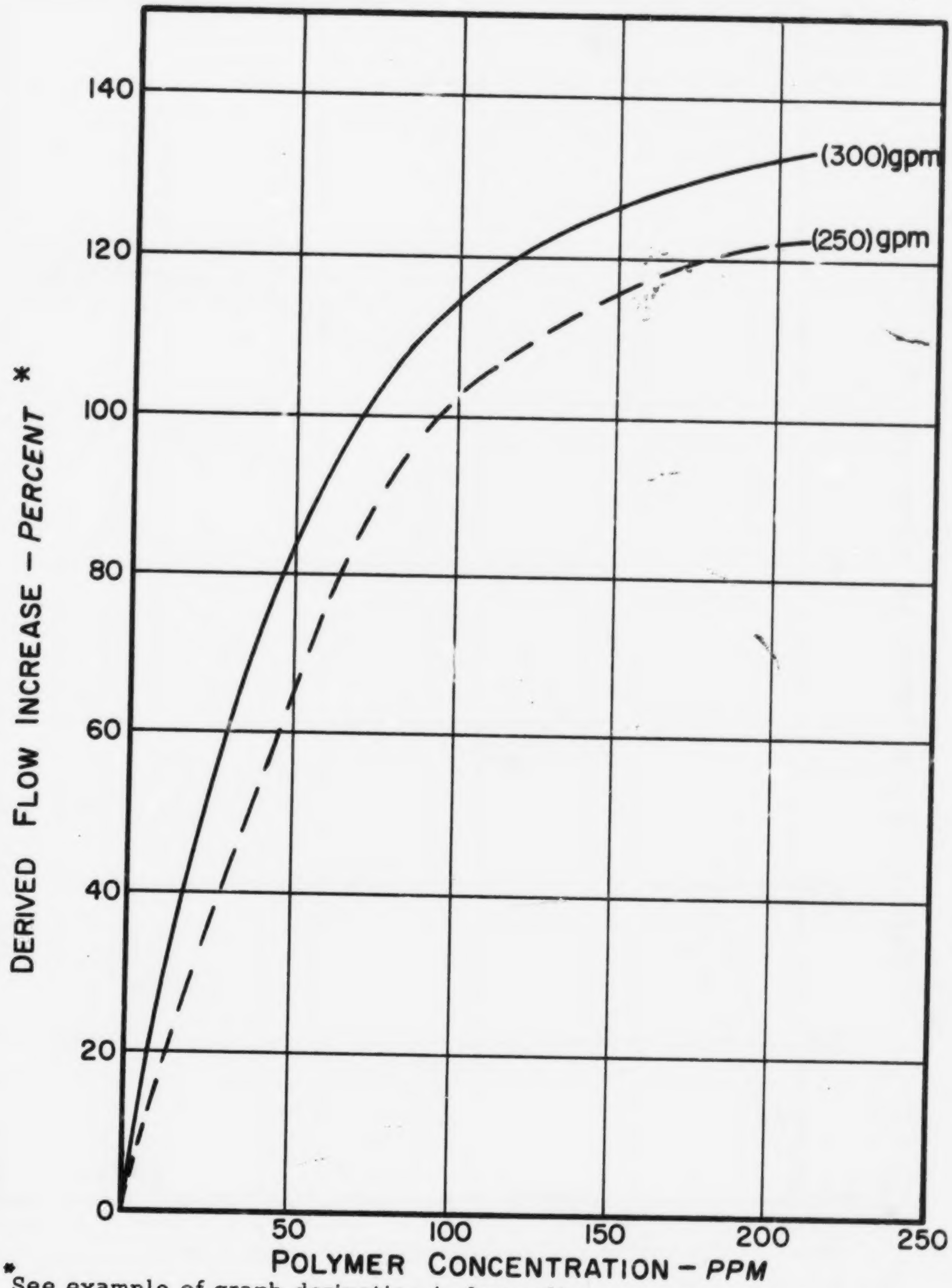
*See example of graph derivation in Appendix.

Figure 36. WSR-301 in Six-Inch Test Facility at 38°F in Water.



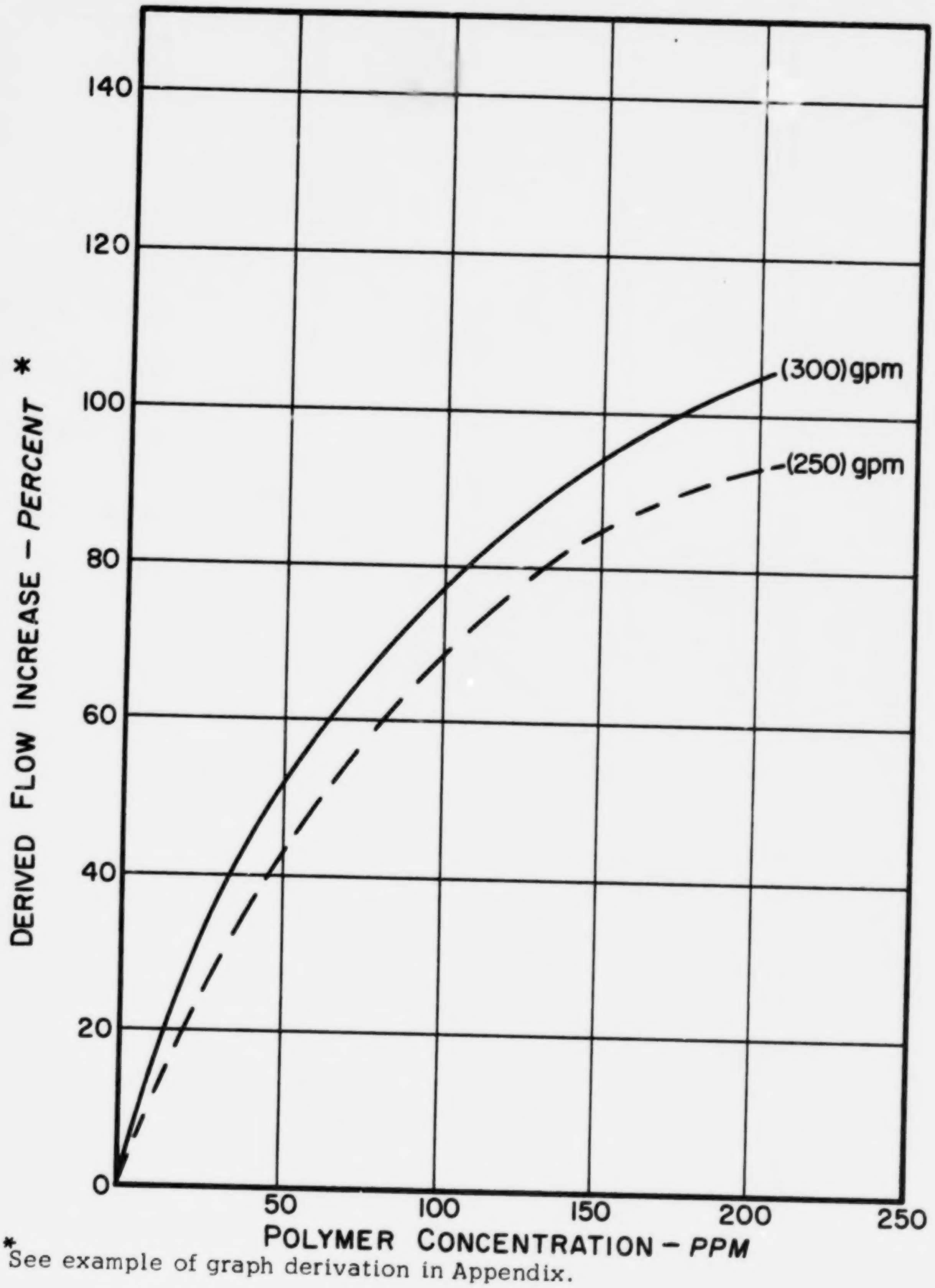
*See example of graph derivation in Appendix.

Figure 37. WSR-301 in Six-Inch Test Facility at 70⁰F in Water.



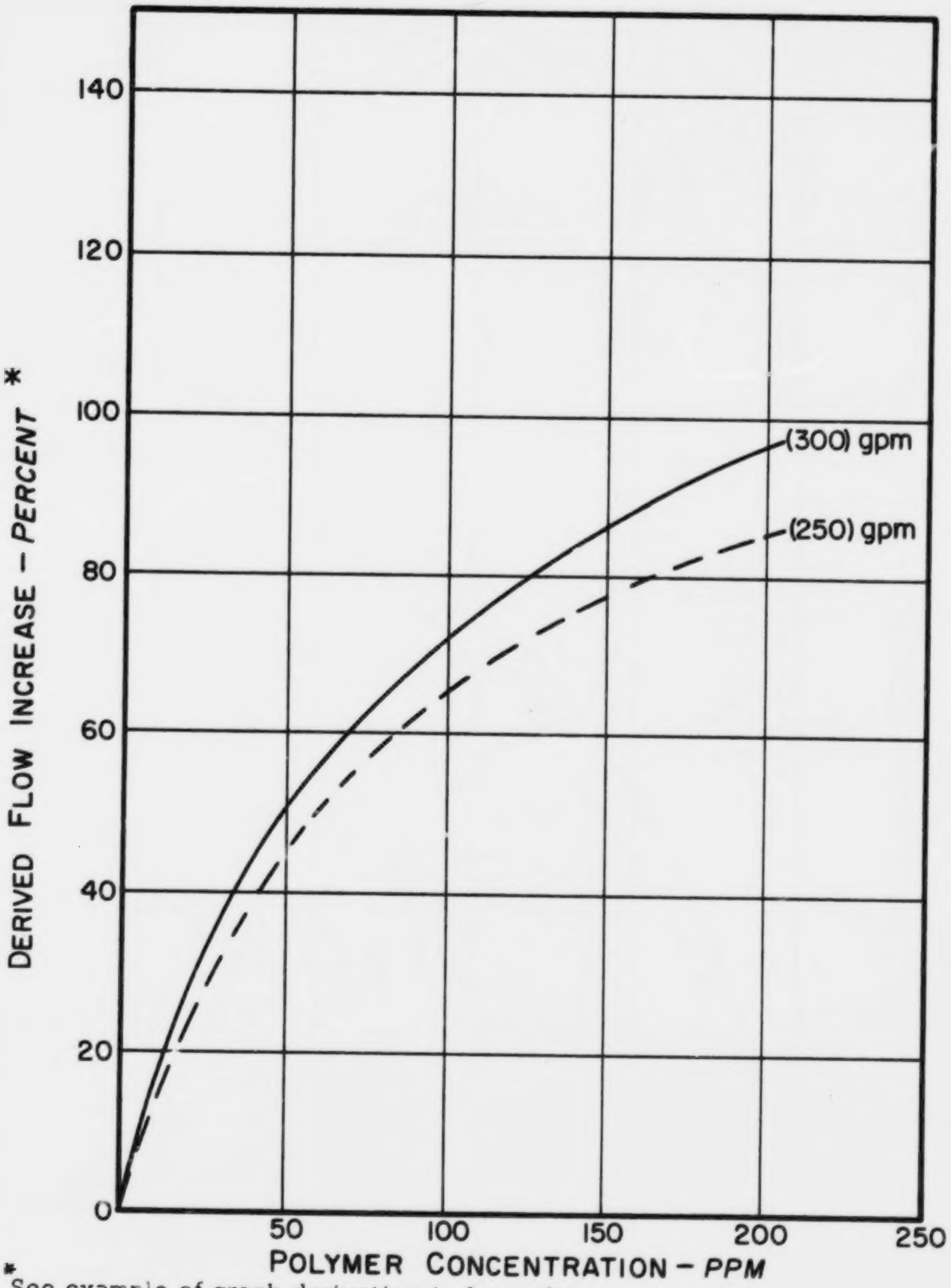
*See example of graph derivation in Appendix.

Figure 38. WSR-301 in Six-Inch Test Facility at 90^0F in Water.



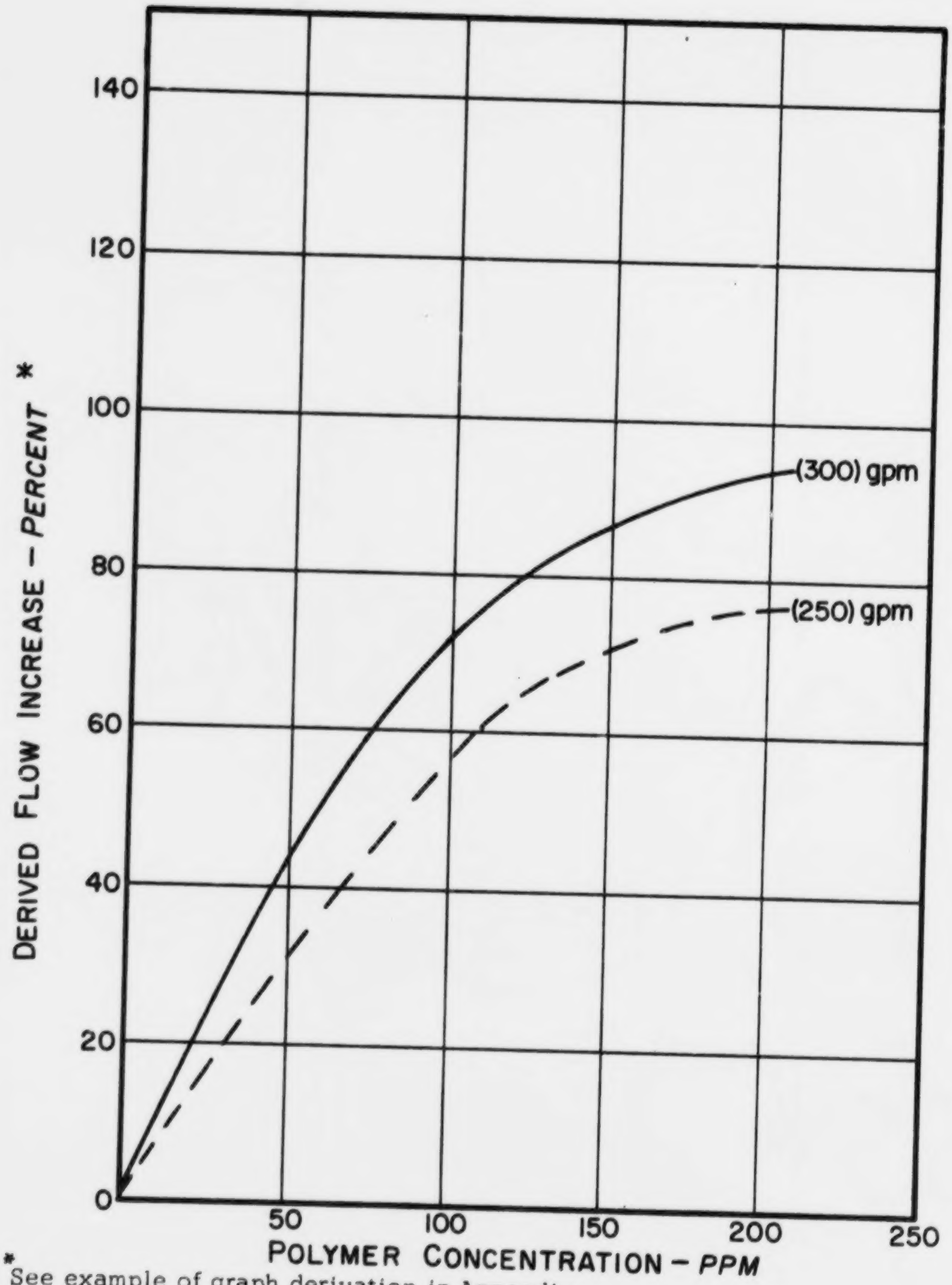
*See example of graph derivation in Appendix.

Figure 39. WSR-301 in Six-Inch Test Facility at 38°F in Sewage (3ml/l Settleable Solids).



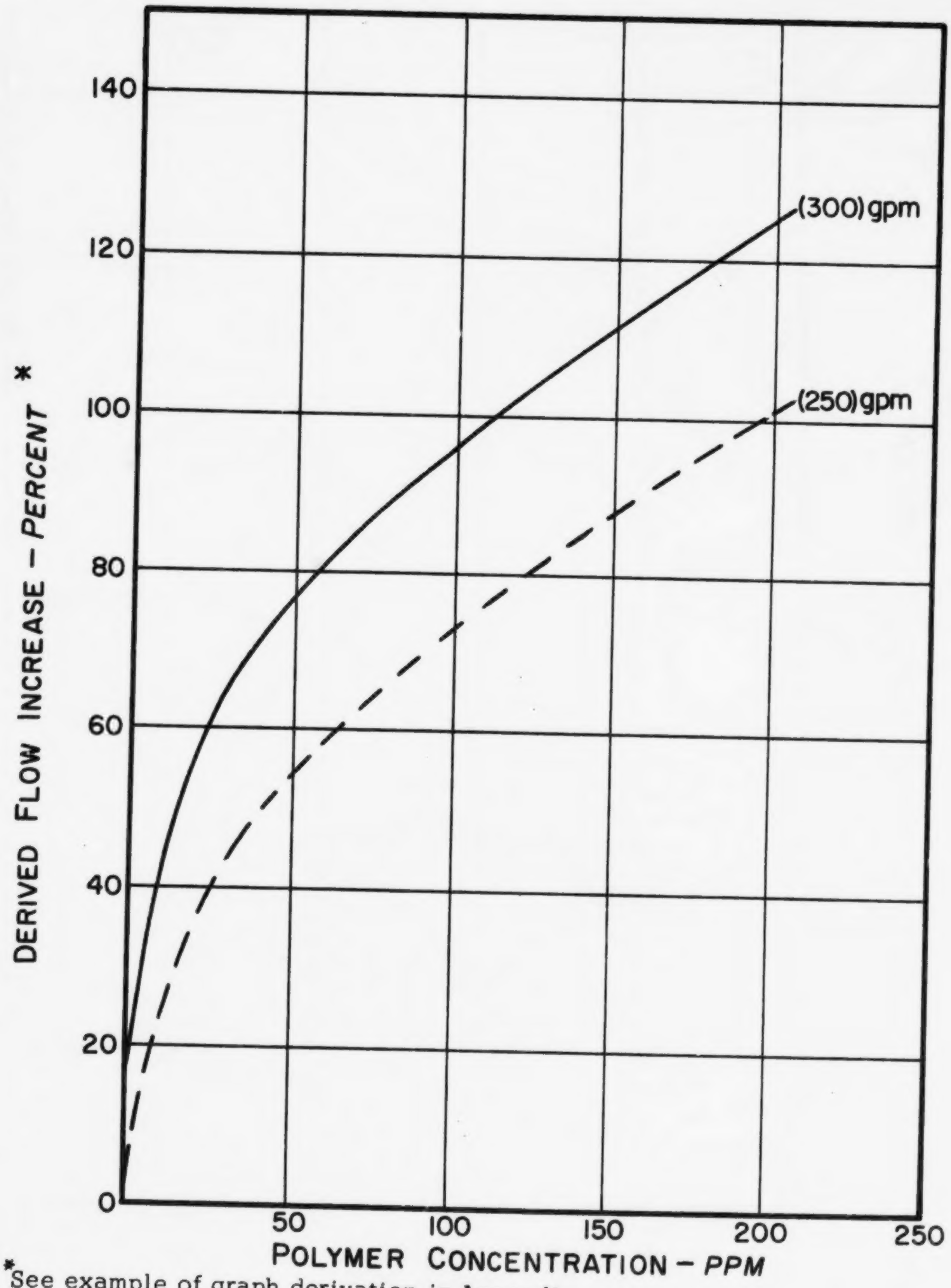
*See example of graph derivation in Appendix.

Figure 40. WSR-301 in Six-Inch Test Facility at 70°F in Sewage (3 ml/l Settleable Solids).



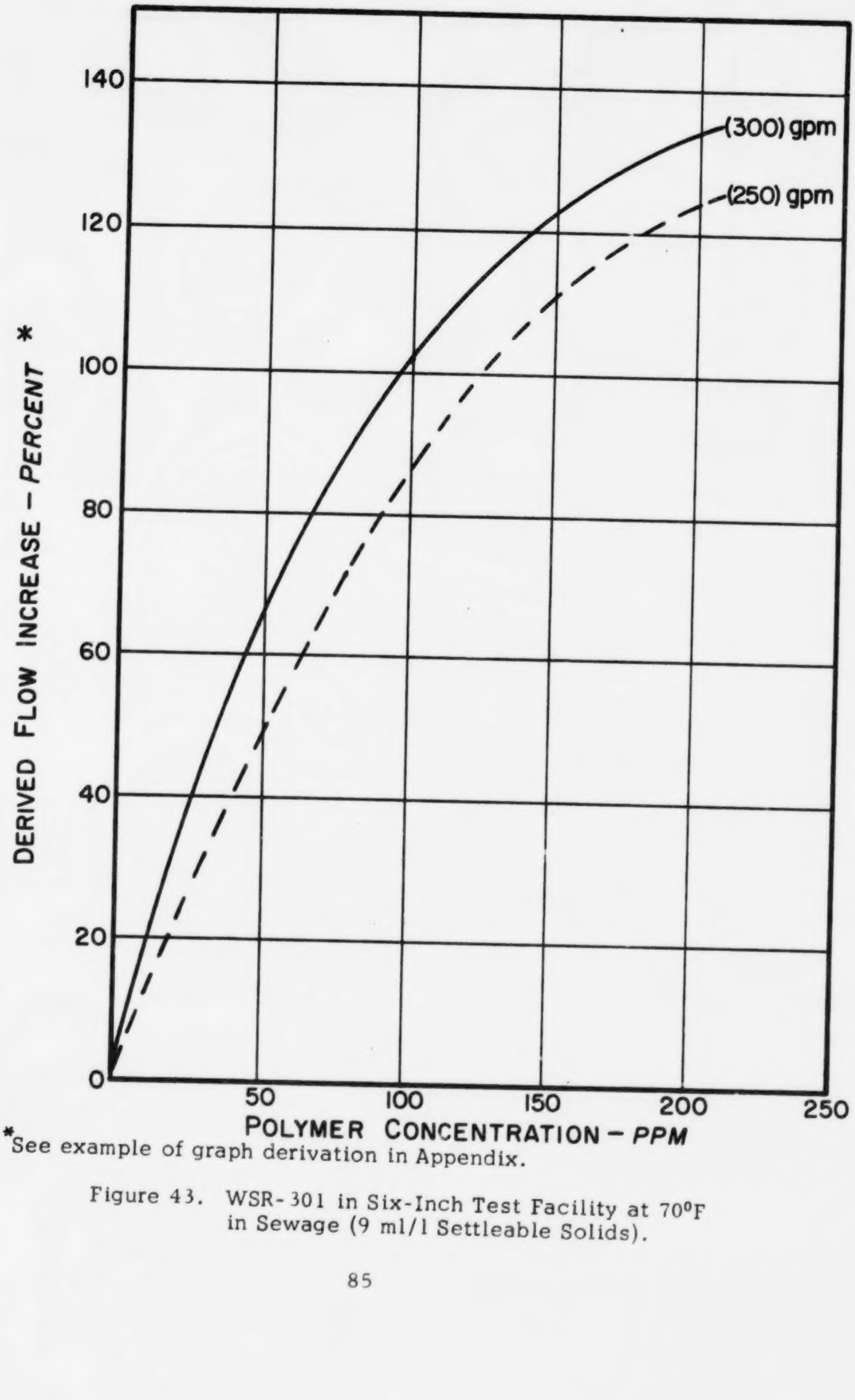
*See example of graph derivation in Appendix.

Figure 41. WSR-301 in Six-Inch Test Facility at 90°F in Sewage (3 ml/l Settleable Solids).



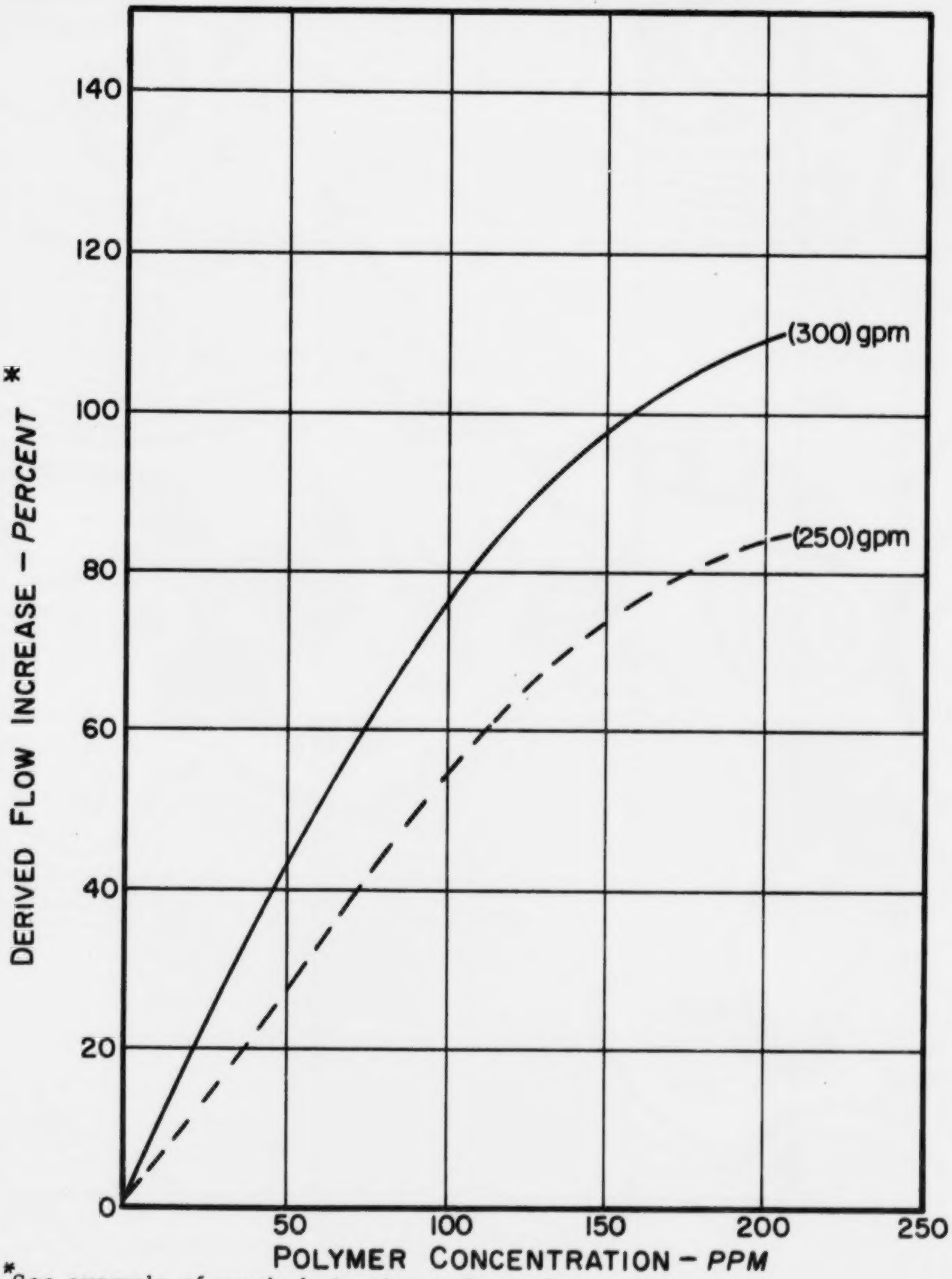
*See example of graph derivation in Appendix.

Figure 42. WSR-301 in Six-Inch Test Facility at 38^{0}F in Sewage (9 ml/l Settleable Solids).



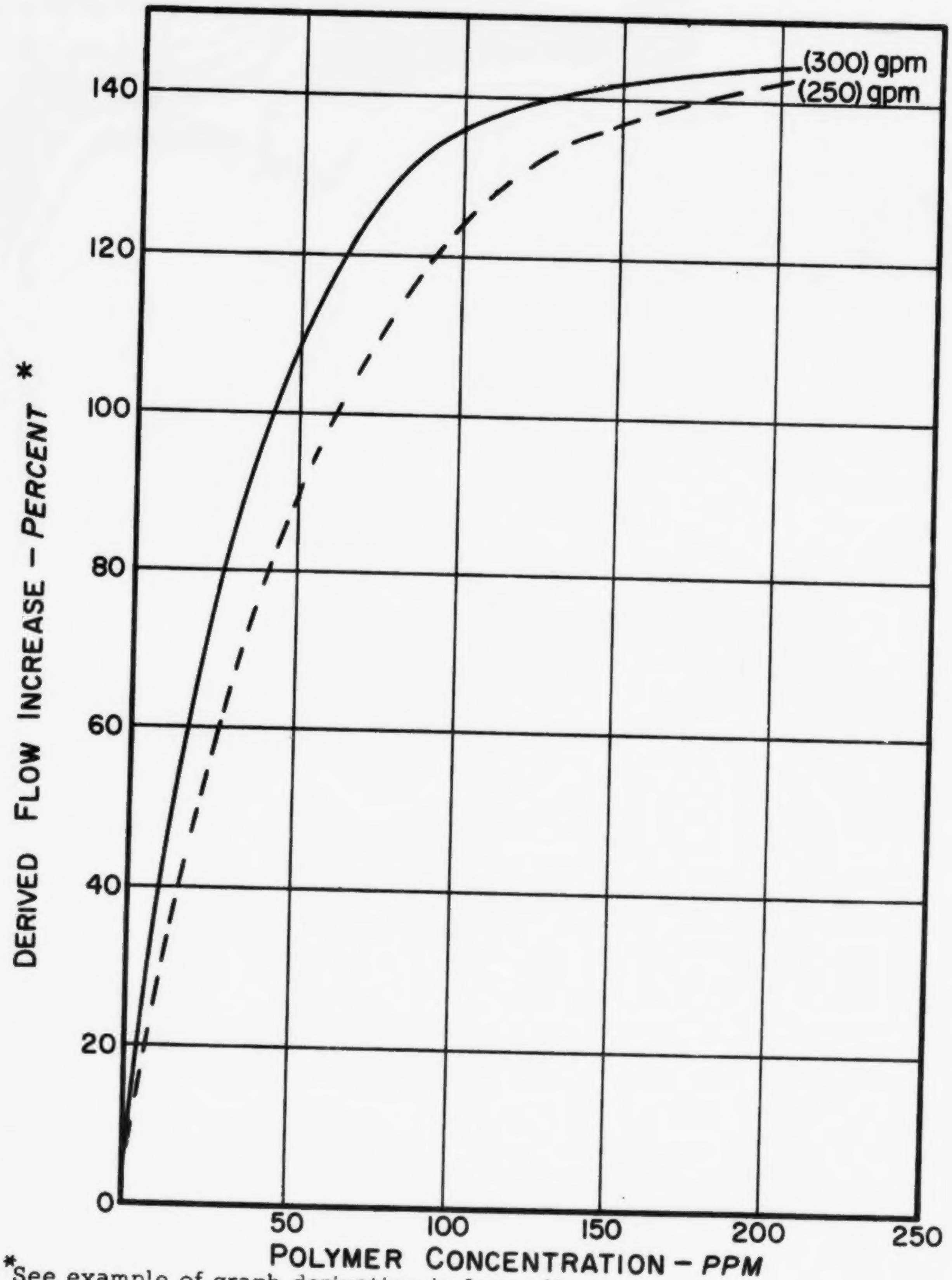
*See example of graph derivation in Appendix.

Figure 43. WSR-301 in Six-Inch Test Facility at 70°F in Sewage (9 ml/l Settleable Solids).



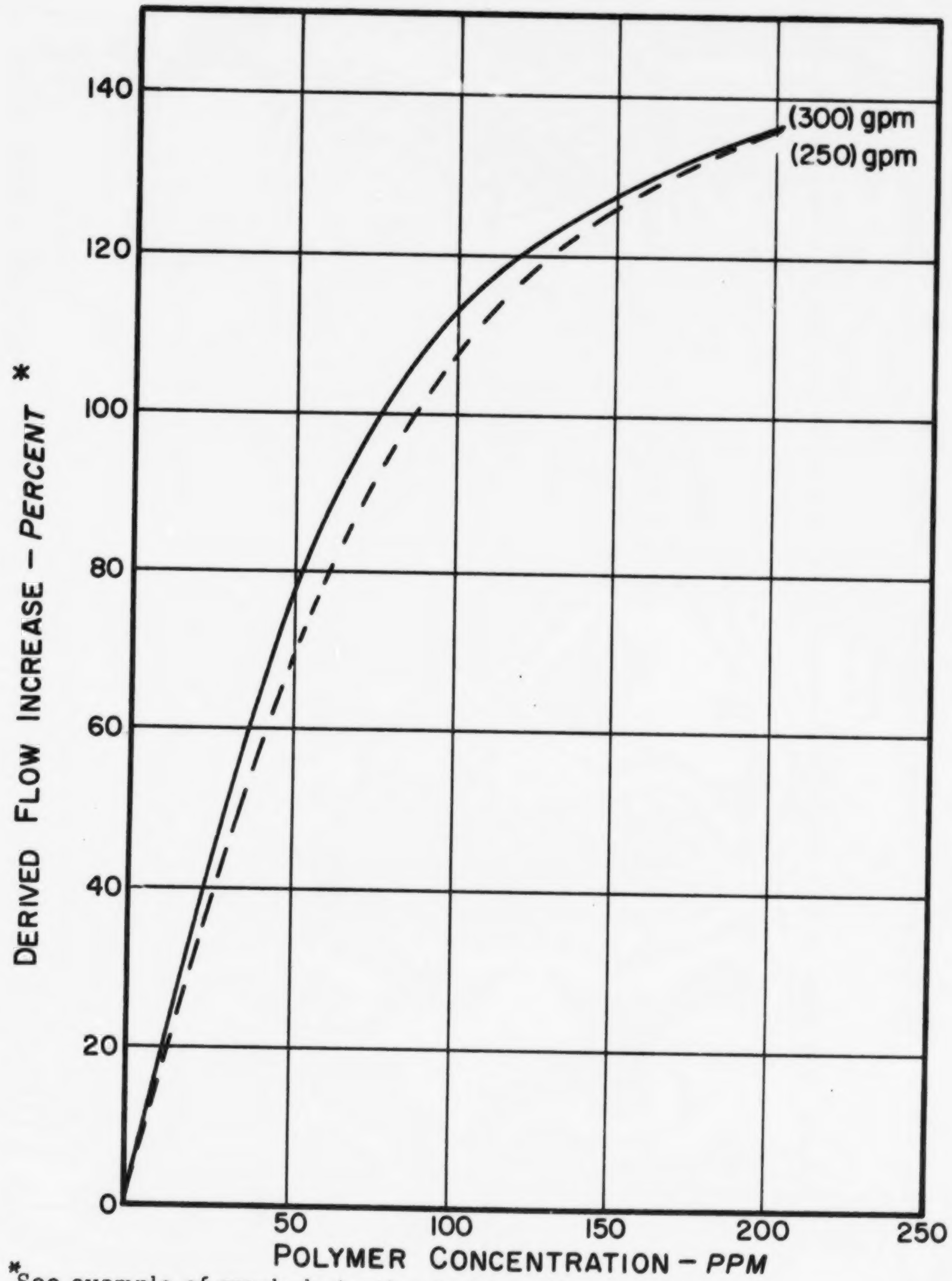
*See example of graph derivation in Appendix.

Figure 44. WSR-301 in Six-Inch Test Facility at 90°F in Sewage (9 ml/l Settleable Solids).



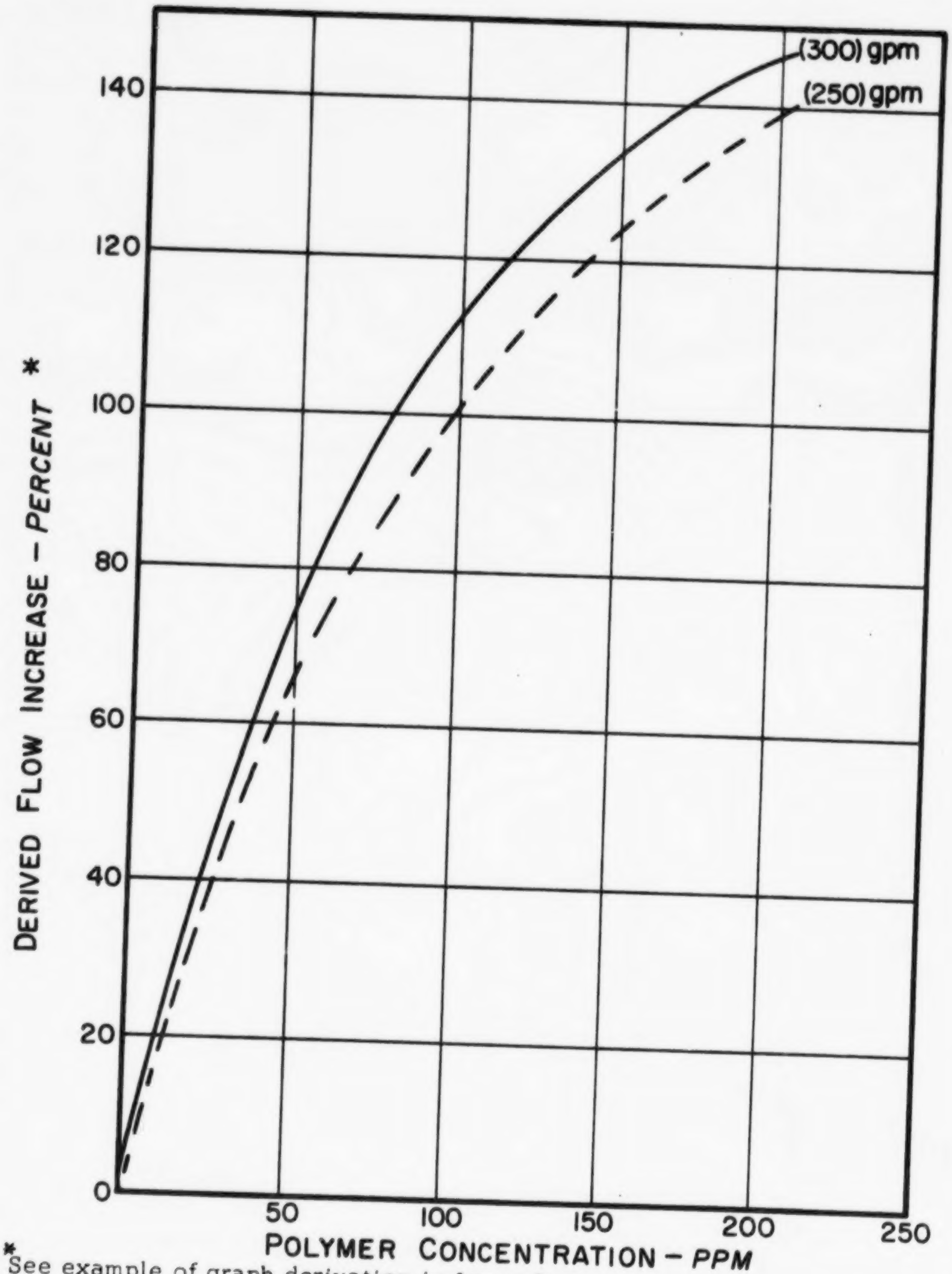
*See example of graph derivation in Appendix.

Figure 45. Polyox Coagulant-701 in Six-Inch Test Facility at 38⁰F in Water.



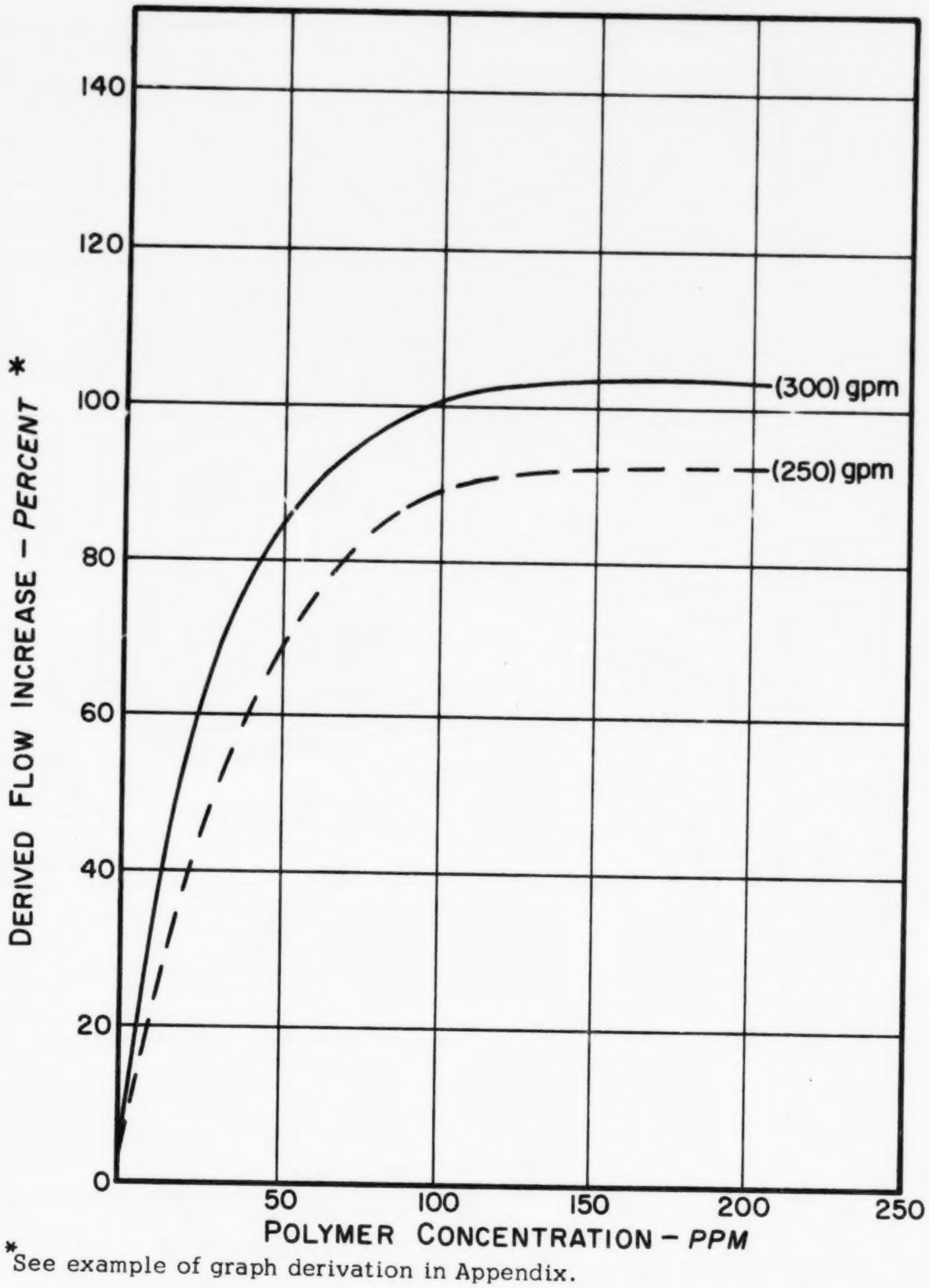
*See example of graph derivation in Appendix.

Figure 46. Polyox Coagulant-701 in Six-Inch Test Facility at 73°F in Water.



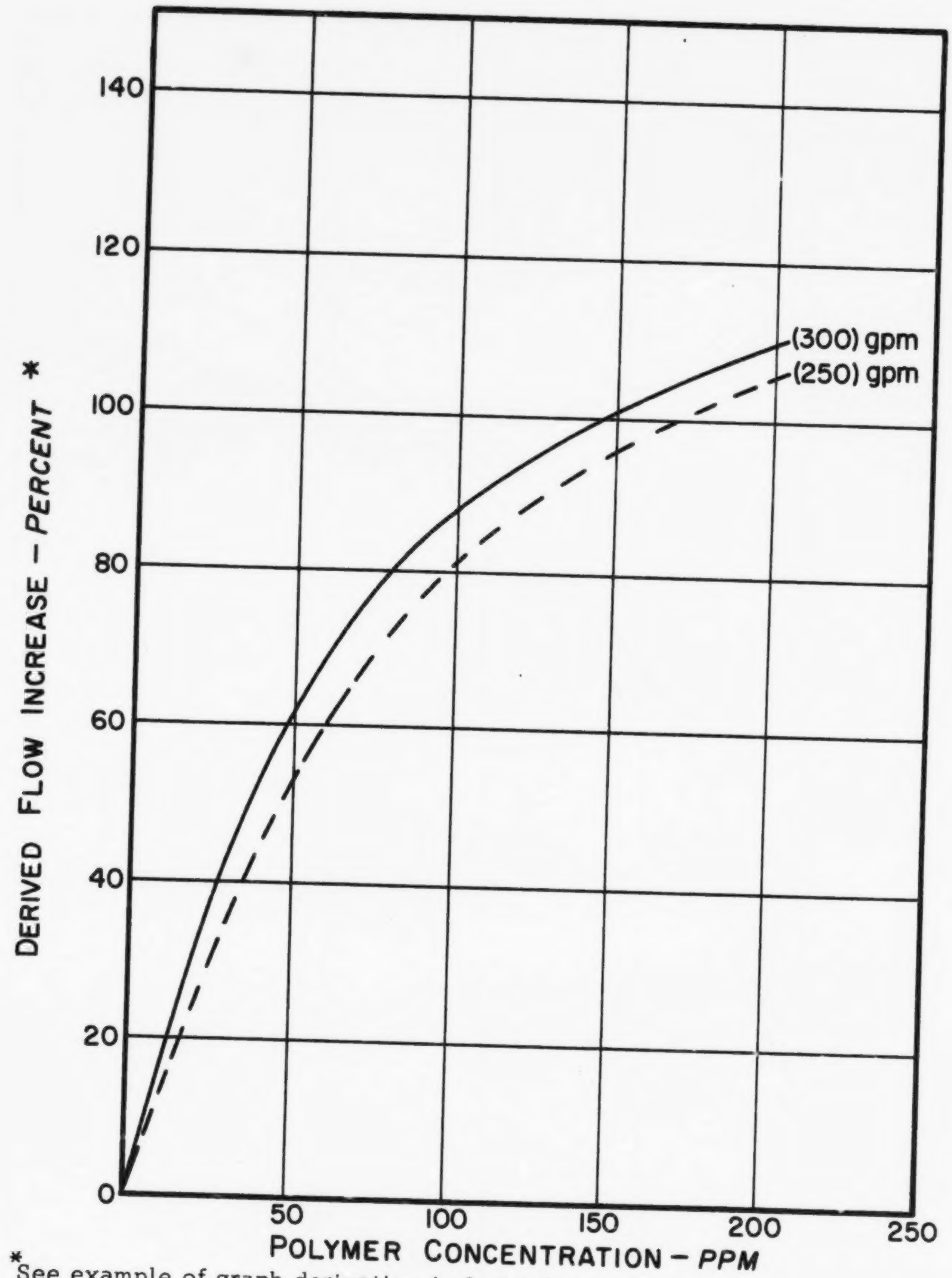
*See example of graph derivation in Appendix.

Figure 47. Polyox Coagulant-701 in Six-Inch Test Facility at 90°F in Water.



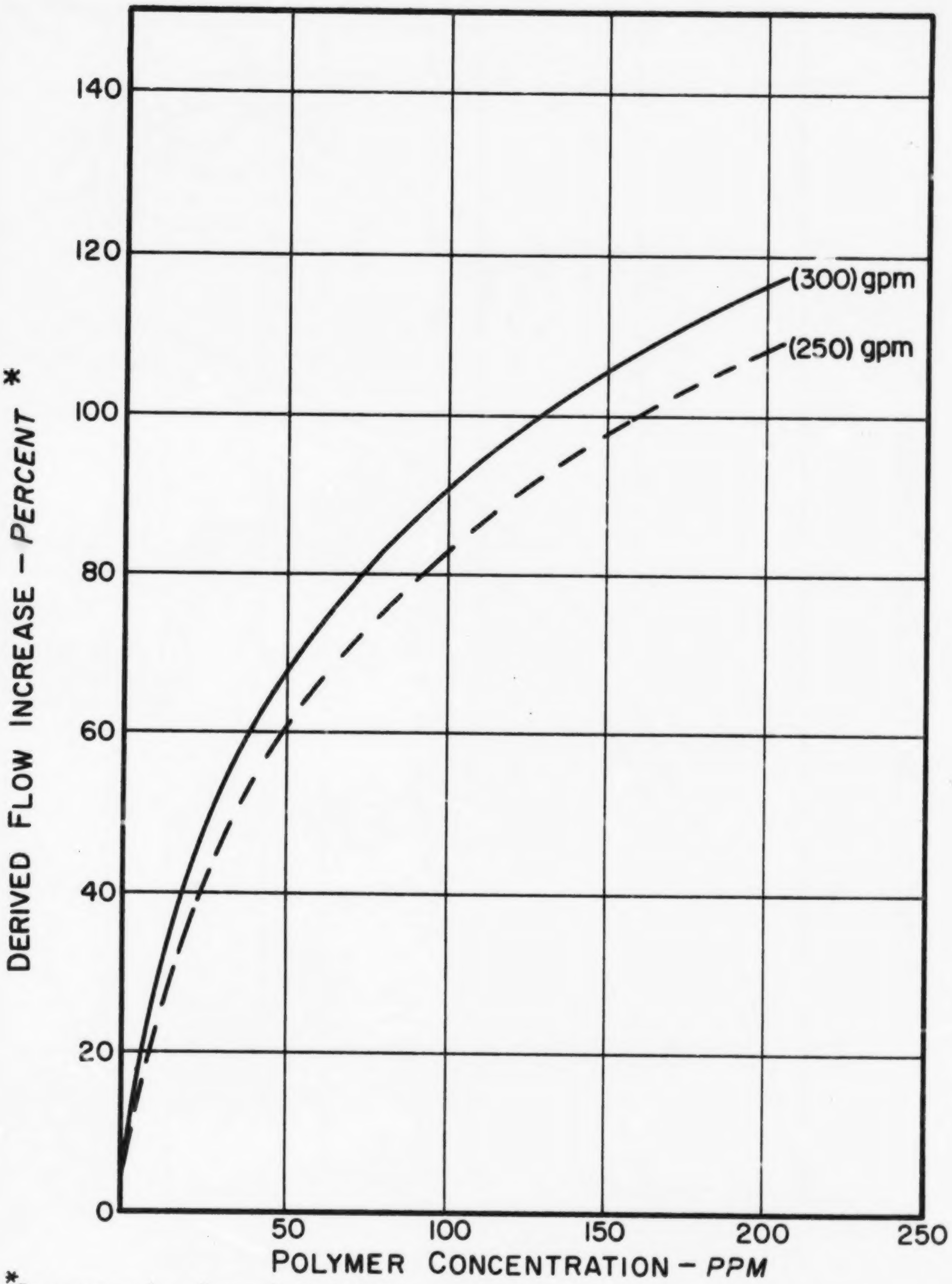
*See example of graph derivation in Appendix.

Figure 48. Polyox Coagulant-701 in Six-Inch Test Facility at 38°F in Sewage (3 ml/l Settleable Solids).



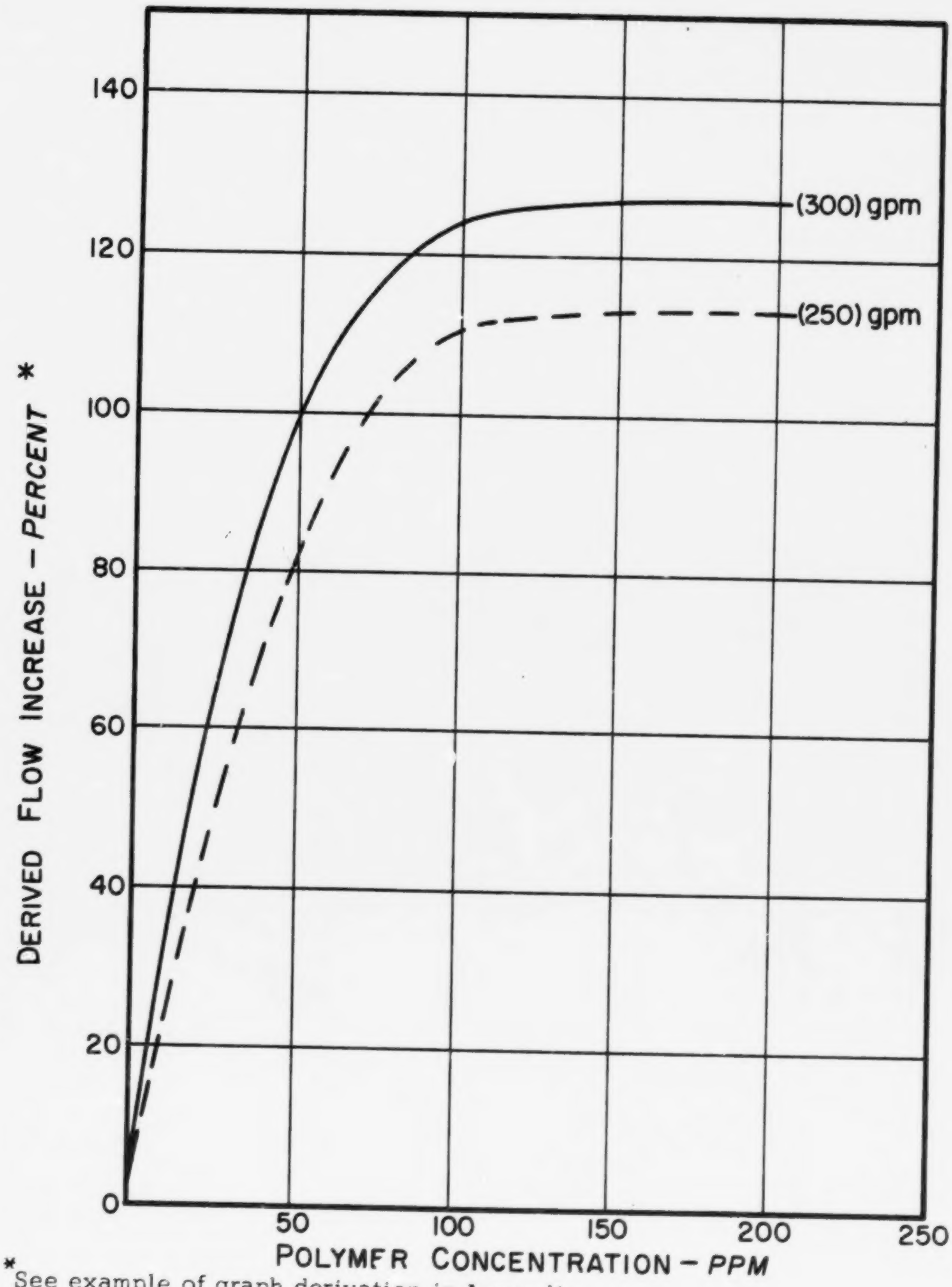
*See example of graph derivation in Appendix.

Figure 49. Polyox Coagulant-701 in Six-Inch Test Facility at 73°F in Sewage (3ml/l Settleable Solids).



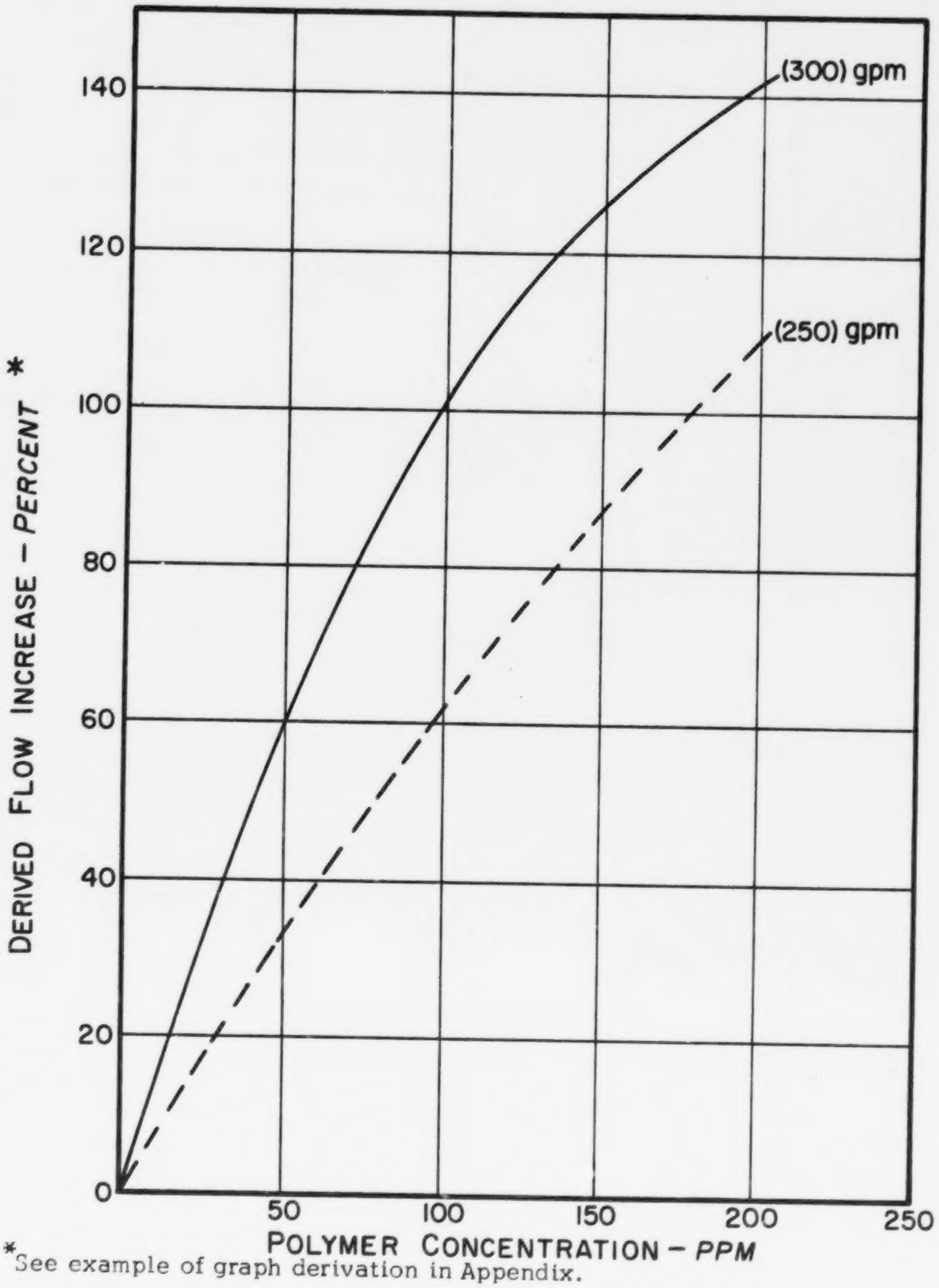
*See example of graph derivation in Appendix.

Figure 50. Polyox Coagulant-701 in Six-Inch Test Facility at 90°F in Sewage (3 ml/l Settleable Solids).



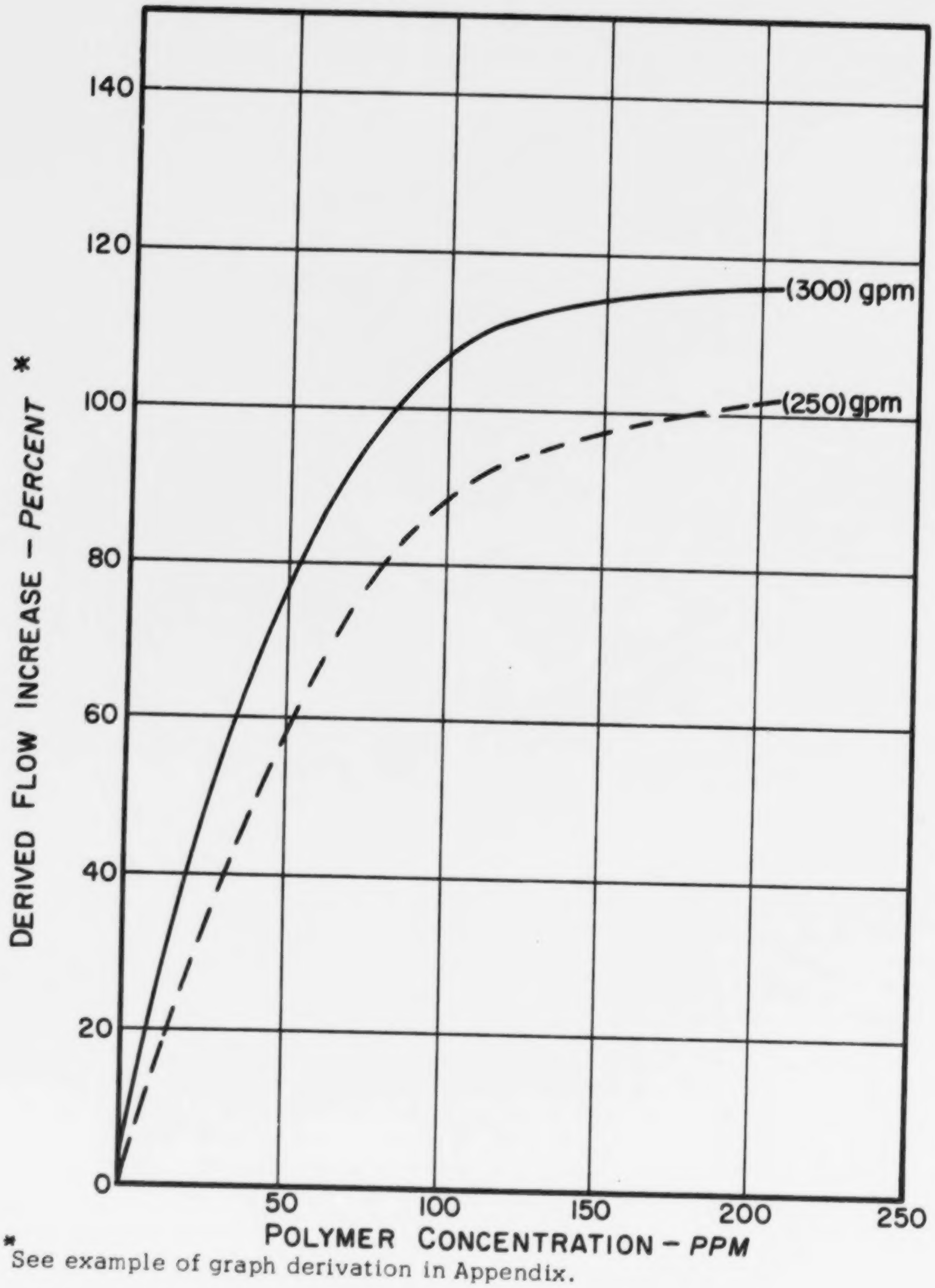
*See example of graph derivation in Appendix.

Figure 51. Polyox Coagulant-701 in Six-Inch Test Facility at 38°F in Sewage (9 ml/l Settleable Solids).



*See example of graph derivation in Appendix.

Figure 52. Polyox Coagulant-701 in Six-Inch Test Facility at 73^{0}F in sewage (9 ml/l Settleable Solids).



*See example of graph derivation in Appendix.

Figure 53. Polyox Coagulant-701 in Six-Inch Test Facility at 90°F in Sewage (9 ml/l Settleable Solids).

The four polymers selected for further consideration as a result of the initial tests performed in the six-inch facility were: Polyox Coagulant-701, WSR-301, AP-30 and FR-4. Subsequent to this selection, a more detailed performance evaluation and further testing was done on these four polymers to provide as much information as possible for incorporation in the full-scale field tests.

The flow increase of the system using FR-4 was not as great as that achieved by the other three additives under any of the flow conditions tested. It can be seen in Figure 30 that the maximum flow increase, approximately 40 percent, occurred at a temperature of 70°F. The additive was quite sensitive to the temperature of the base fluid as indicated by the reduction in flow increase at temperatures of 38°F and 90°F.

The optimum concentration of AP-30 was determined to be approximately 250 milligrams per liter when compared with the base fluid. This additive varied about six percent in its flow-increasing ability over the temperature range from 38° to 90°F. The average derived flow increase obtained by using AP-30 was about 113 percent (2.13 times original flow). The advantages of this polymer were its stability over the temperature range tested and its relative inertness to the sewage. The main disadvantages were cost and the relatively high concentrations required as compared with the polyethylene oxide based additives tested. Nevertheless, AP-30 polymer could be induced into the sewer line with relatively inexpensive equipment.

The remaining two polymers tested in the six-inch test facility were the polyethylene oxides, WSR-301 and Polyox Coagulant-701. These two polymers were tested in water and controlled sewage concentration of three and nine milliliters per liter settleable solids. The reactions of WSR-301 and Polyox Coagulant-701 to both temperature and sewage concentration made the analysis of the test results rather complex (Figures 21 through 25). Both additives, however, were extremely effective with respect to increasing the flow of sewer systems.

The analysis of the test data for WSR-301 and Polyox Coagulant-701 showed similar flow characteristics. WSR-301 at 200 milligrams per liter varied from a derived flow increase of 125 percent (2.25 times original flow) at 38°F to a maximum of 135 percent at 70°F then decreasing to 110 percent at 90°F with 9 milliliter per liter settleable solid sewage. The test data appeared to indicate that three milliliters per liter of settleable solids had more effect on this additive than did nine milliliters per liter. The same phenomena with sewage concentration occurred with Polyox Coagulant-701; however, 701's ability to increase flow varied more with temperature. At 9 milliliters per liter settleable solids concentration, the derived flow increase for Polyox Coagulant-701 varied from 125 percent at 38°F to 141 percent at 73°F and then dropped to 117 percent at 90°F.

In general the results showed that polymer effectiveness, to increase flow at a constant head or reduce the frictional losses, is dependent upon sewage characteristic and the sewage temperature.

Polymer Injection Point Test Results

Tests were performed in the four-inch test facility to determine the affect of the point of injection with respect to the location of specific pipe fittings used in sewers. These tests were performed with AP-30, FR-4 WSR-301 and Polyox Coagulant-701. The restrictions tested were of two general types, such as the long- and short-radius elbows where flow restrictions occur as a result of flow deformation, and wyes and tee where flow restrictions occur due to both flow deformation and turbulence.

To facilitate the analysis, the data was normalized before plotting, which resulted in the definition of a performance index (ϵ) that was the ratio of the flow increase due to injection at point "i" ($i = 1$ to 4) to the maximum flow increase experienced. Also, the distance from the injection point to the restriction is expressed in equivalent pipe diameters, L/D, where L is the length of the pipe and D is the pipe diameter.

Figure 54 represents the data for all the constrictions tested, including results of the square sewer line tests, which agreed with the circular tests. It should be observed that the additive injection point affect was negligible for all the restrictions tested within the L/D range used. Even though the smallest L/D tested was 21, it is felt that this mixing was observed to take place at the restriction itself. It is also possible that all injection points were so close to the restriction that none of the results are valid.

The injection point tests were performed to determine how far upstream it was necessary to inject a polymer in order to relieve a line surcharged by the junction of other lines which were not surcharged. Test results showed that location of the polymer injection point is not critical, and that the polymer slurry need be injected only slightly upstream of the surcharged point.

Affects of Solid Concentrations on Polymers

During rainstorms, the heavy flow of fluid through combined sewers can flush accumulated material off sewer walls resulting in settleable solids as high as 1,551 milligrams per liter. Previous tests indicated that Polyox Coagulant-701 and WSR-301 were affected by solids in sewage, resulting in a reduction in the amount of derived flow increase obtained. It appeared that a portion of the polymers used to increase flow was sacrificed to coagulate the sewage solids. This same coagulating phenomena may occur with sand, silt, and sludge during the flushing periods.

Of the six polymers tested, three were significantly better friction reducers, Polyox Coagulant-701, WSR-301, and AP-30. Of the three best polymers, two were affected by sewage, (e.g., some deterioration in friction reduction performance was noticed when tested in sewage instead of water). Therefore, these two polymers, Polyox Coagulant-701 and WSR-301, were tested additionally in sewage with high concentrations of solids at ambient temperature.

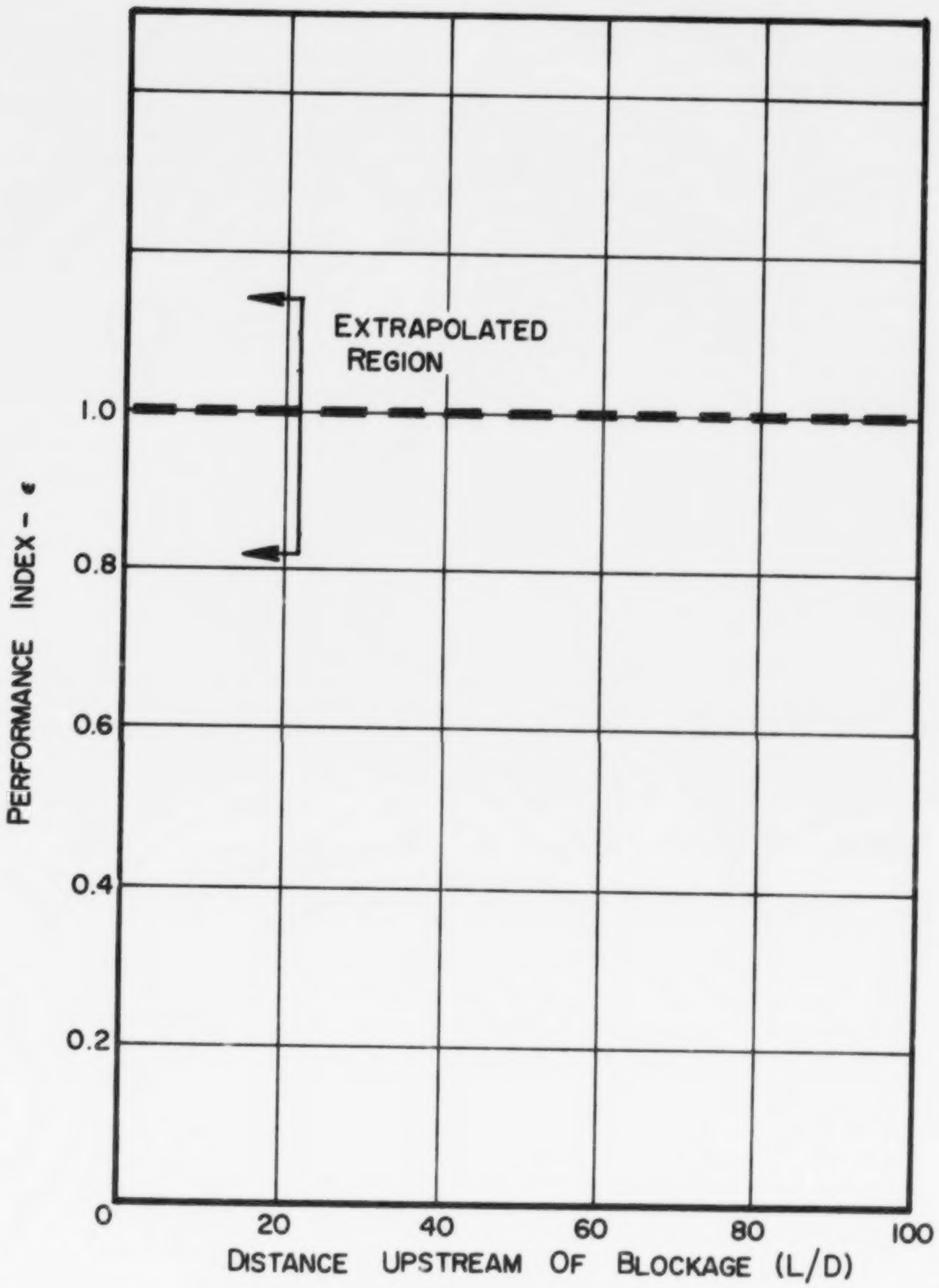


Figure 54. Injection Point Affect on Sewage System Flow Constrictions.

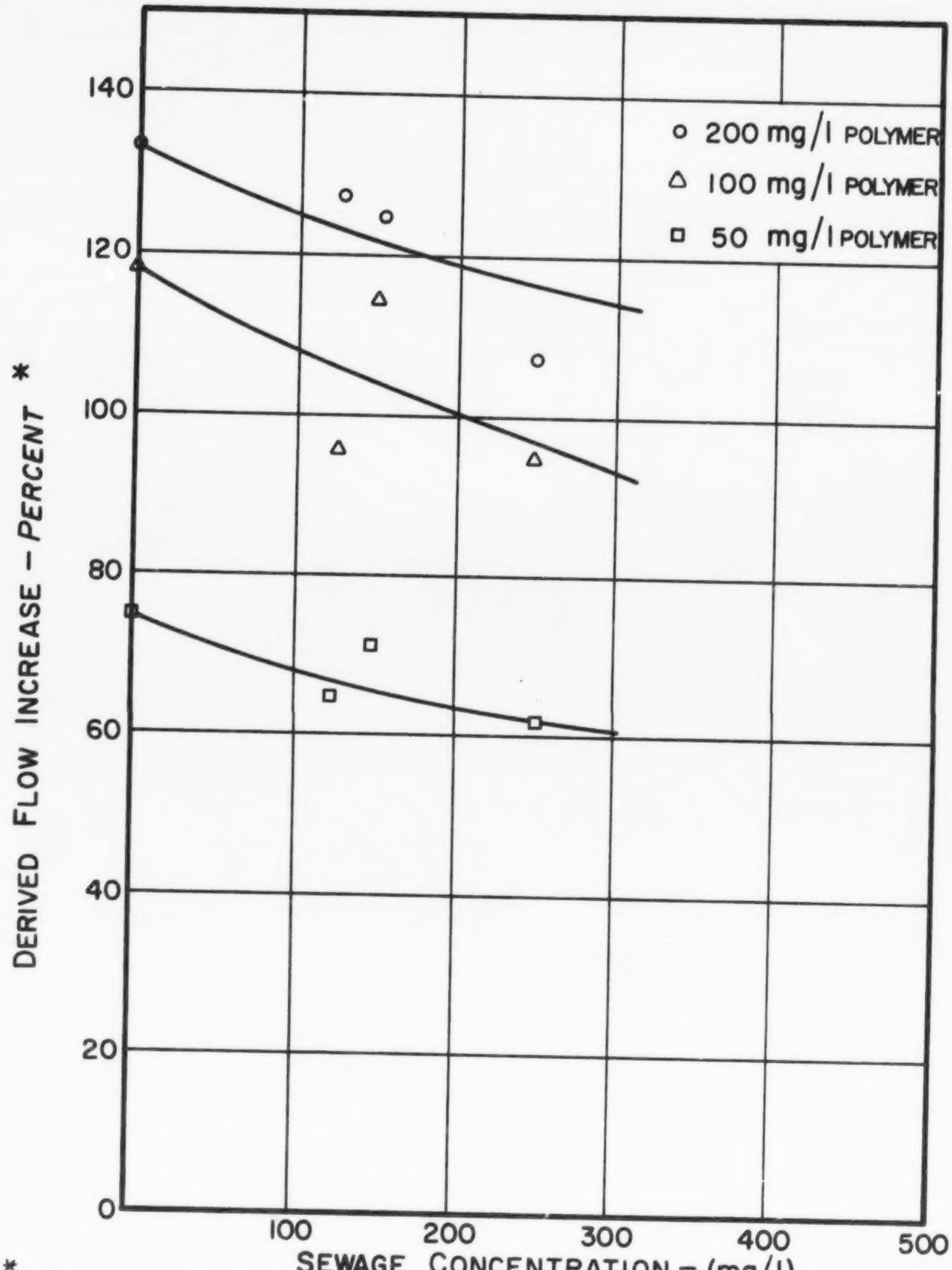
Shown in Figures 55 through 58 are the results of the additional tests using high concentrations of settleable solids and three concentrations of each polymer, 50 milligrams per liter, 100 milligrams per liter, and 200 milligrams per liter. The flow increase results were obtained by measuring the flow and pressure drop characteristics and by using a test procedure identical to early tests except that the sewage was neither heated nor cooled.

In sewage with approximately 1,500 milligrams per liter of settleable solids, Polyox Coagulant-701 at 100 milligrams per liter increased the derived flow rate of the sewage by 2.05 times the original flow rate for sewage without polymer (See Figure 57).

In sewage with approximately 1,600 milligrams per liter of settleable solids, WSR-301 at 200 milligrams per liter increased the derived flow rate of the sewage by 2.4 times the original flow rate for sewage without polymer (See Figure 58).

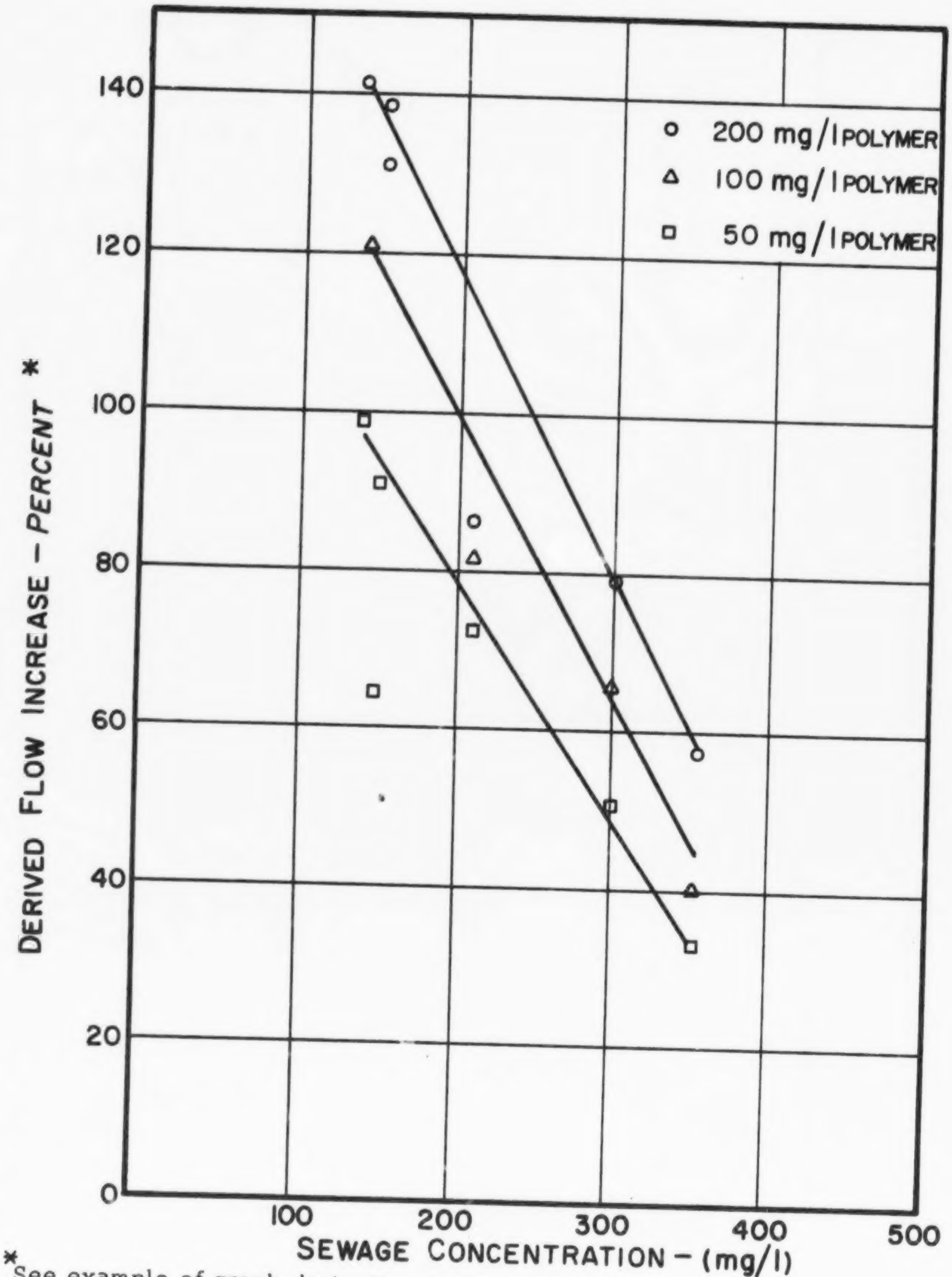
It is anticipated that the settleable solids used in this test had the greatest adverse affect possible on the polymer performance, except in the instances of sludge movement. The heavy solids concentrations in sewers normally consist of large percentages of sand and silt which do not tend to attract the polymers for coagulation like sewage solids. The high concentrations of solids are believed to occur for a relatively short period of time when high sewage flow scours the pipe clean of material that has accumulated since the last heavy flow.

Polymer selection for use in a sewer line should take into consideration the solids concentration in the wastewater. Previous tests showed that one good flow-increasing polymer, AP-30, was not affected by solids, whereas Polyox Coagulant-701 was affected more than WSR-301.



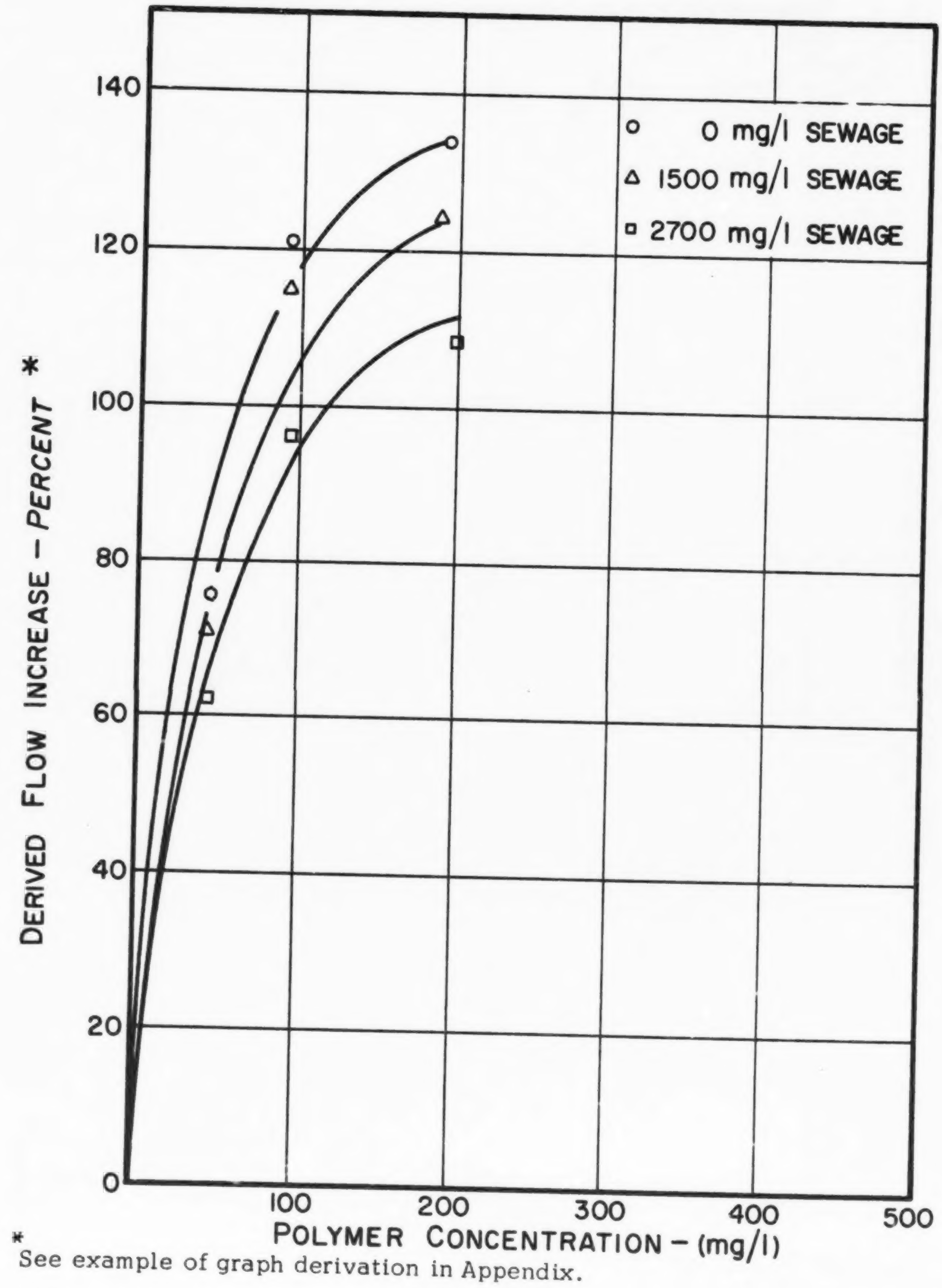
*See example of graph derivation in Appendix.

Figure 55. Percentage Flow Increase vs Sewage Concentration (mg/l) Polyox Coagulant-701 Polymer.



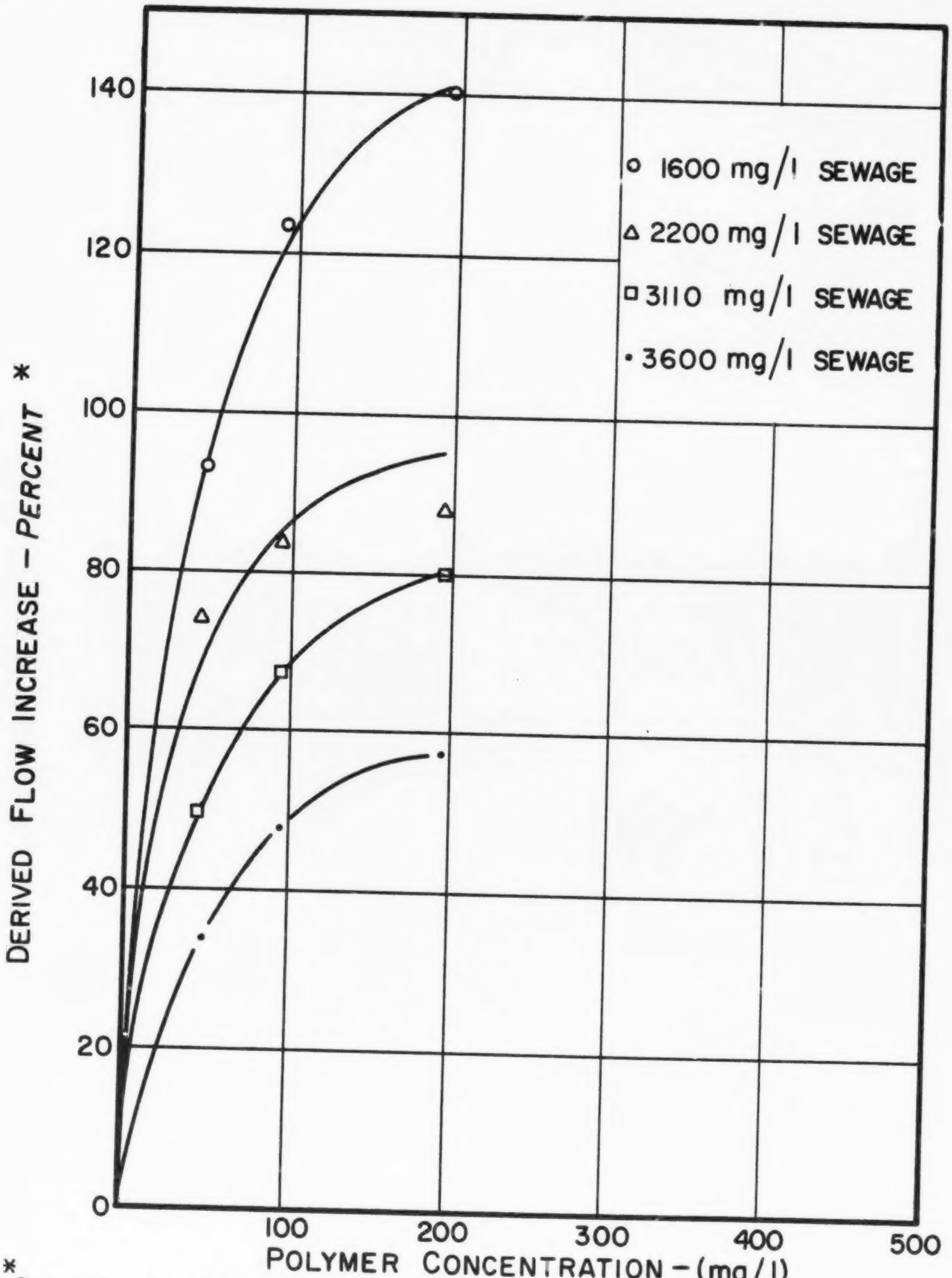
*See example of graph derivation in Appendix.

Figure 56. Percentage Flow Increase vs Sewage Concentration (mg/l) WSR-301 Polymer.



*See example of graph derivation in Appendix.

Figure 57. Polymer (mg/l) vs Percent Increase With a Given Sewage Concentration, Polyox Coagulant-701 Polymer.



*See example of graph derivation in Appendix.

Figure 58. Polymer Concentration (mg/l) vs Percentage Flow Increase With Given Sewage Concentration, WSR-301 Polymer.

SECTION V

FIELD TEST EVALUATION OF POLYMERS

Field evaluation of the use of polymers in sewerage systems consisted of two separate testing operations. The first consisted of testing an existing large-diameter sewer plagued with a surcharged condition through the injection of WSR-301 and Polyox Coagulant-701 polymers.

The second field evaluation was the injection of polymers into the raw sewage at the intake of a secondary type treatment plant so that data on its operation could be obtained.

Large-Diameter Sewer Field Evaluation

Full-scale tests were conducted on a 24-inch diameter concrete sewer line to determine if the use of polymers resulted in flow phenomena similar to that obtained during tests on a six-inch diameter model line.

Site Selection. The selection of the large-diameter test line was based upon the following criteria: 1) frequency of surcharged flow conditions from ground-water infiltration, or inadequacy of line capacity during peak daily flows; 2) suitability for installation of temporary manholes, suitability for instrumentation for measuring flow rates, temperature, and static head on pipe, and suitability for obtaining sewage samples for laboratory analysis; 3) minimum number of branch lines between the point of polymer injection and the downstream monitoring point with minimal flows: 4) ease of access with injection equipment; and 5) availability to laboratory facilities.

After considering a number of potential sites, the most ideal site was determined to be a 24-inch interceptor sewer line in the northern portion of the City of Dallas collection system. This line is constructed from 24-inch concrete sewer pipe laid at a grade of 0.32 percent with the exception of about 170 feet which is at a 0.25 percent grade.

The 4,100-foot test section length receives flow from a 36-inch interceptor line from the City of Richardson and discharges into a 30-inch diameter pipe downstream. During peak daily flow periods, this line is surcharged to depths between four and eight feet above the top of the pipe. After heavy rainfalls, the increased flow resulting from ground-water infiltration is released directly into Cottonwood Creek by a bypass valve. The frequency and magnitude of surcharged flow conditions influenced the selection of this sewer as the demonstration site for field evaluation.

Site Instrumentation. Figure 59 delineates the plan and profile of the pipe section used in the large diameter flow test demonstration, including the three temporary manholes installed over the 24-inch line and one manhole installed over the 36-inch line to permit instrumentation.

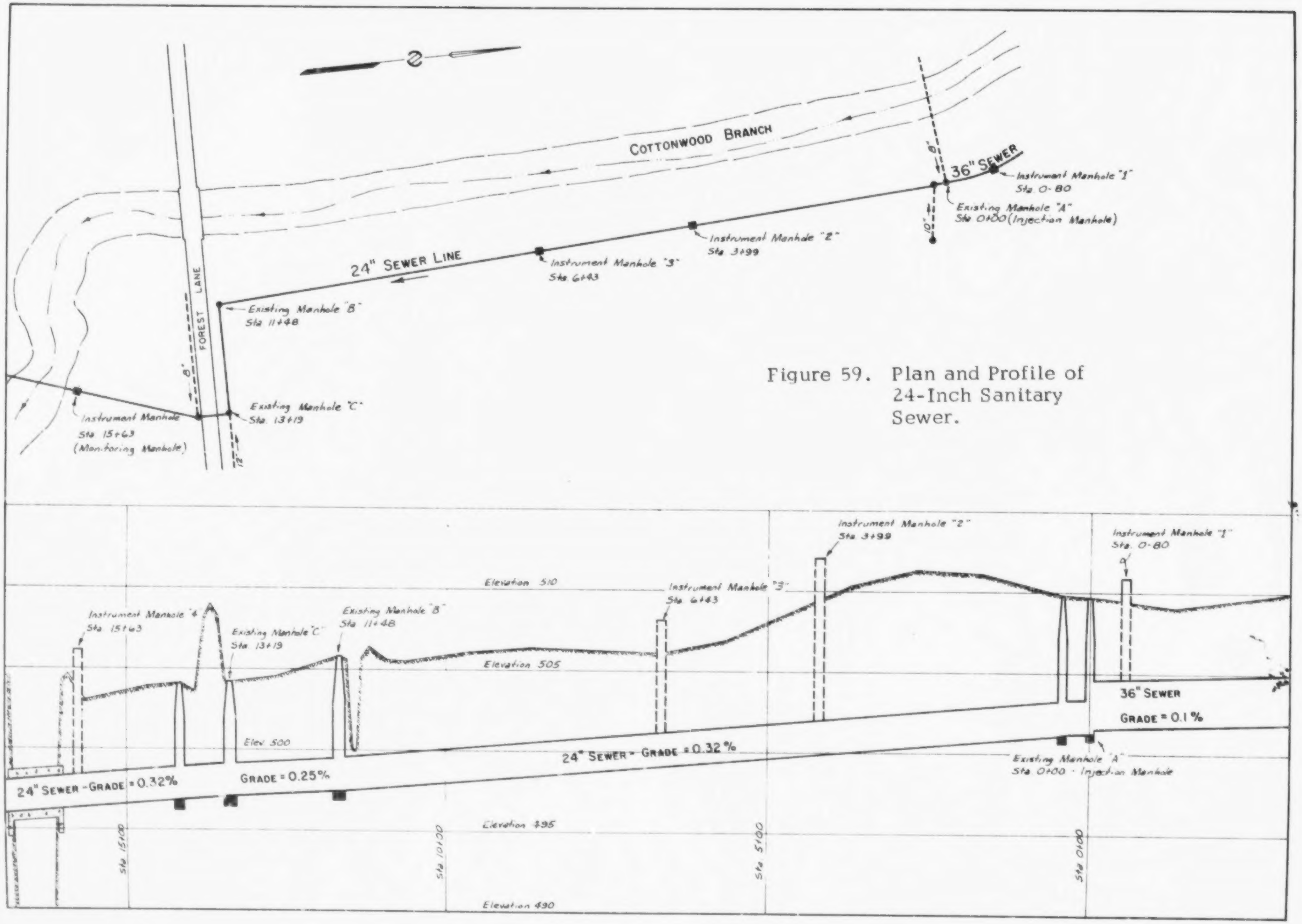

COTTONWOOD BRANCH
36" SEWER
Instrument Manhole "1" Sta 0-80
Existing Manhole "A" Sta 0+00 (Injection Manhole)
Instrument Manhole "2" Sta 3+99
Instrument Manhole "3" Sta 6+43
24" SEWER LINE
Existing Manhole "B" Sta 11+48
FOREST LANE
Existing Manhole "C" Sta 13+19
Instrument Manhole Sta 15+63 (Monitoring Manhole)
8'
10'
12'
Instrument Manhole "4" Sta 15+63
Existing Manhole "C" Sta 13+19
Existing Manhole "B" Sta 11+48
Instrument Manhole "3" Sta 6+43
Instrument Manhole "2" Sta 3+99
Instrument Manhole "1" Sta 0-80
Elevation 510
Elevation 505
Elev 500
Elevation 495
Elevation 490
36" SEWER
GRADE = 0.1%
24" SEWER - GRADE = 0.32%
GRADE = 0.25%
24" SEWER - GRADE = 0.32%
Existing Manhole "A" Sta 0+00 - Injection Manhole
Sta 15+00
Sta 10+00
Sta 5+00
Sta 0+00

Figure 59. Plan and Profile of 24-Inch Sanitary Sewer.

The manholes (Figure 60) were constructed by excavating soil from over the top of the sewer pipe and installing a section of 5-foot diameter corrugated metal pipe with the bottom end cut to fit the curvature of the sewer pipe. At each manhole, two 2-inch taps were made in the sewer pipe and 2-inch pipes inserted. Concrete was then placed around the 2-inch pipes and over the top of the sewer pipe to obtain a flat bottom. By installing valves and fittings, one of the taps was rigged to obtain sewage temperature and sewage samples and the other tap was used to obtain the fluctuations in static head on the line.

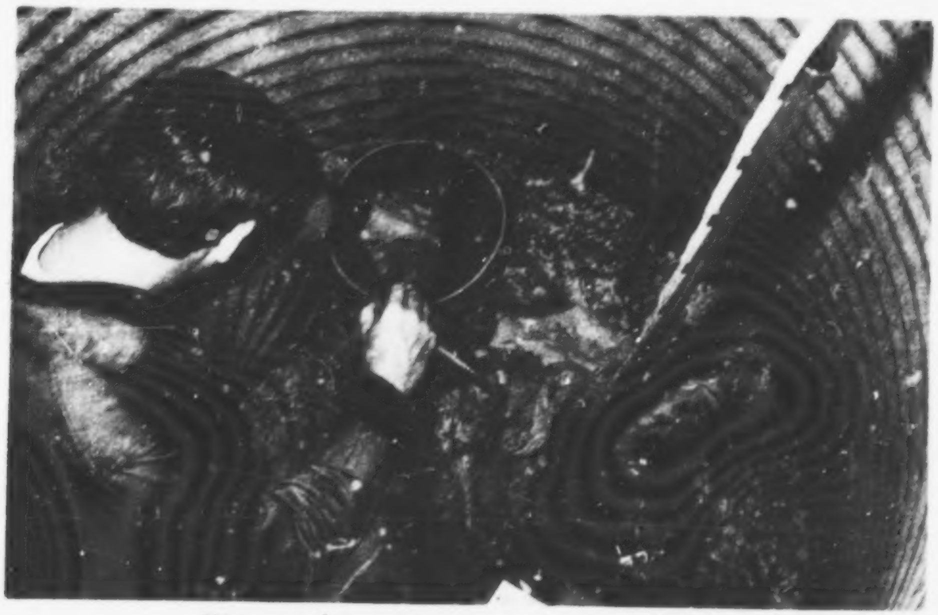


Figure 60. Monitoring Manhole.

Two techniques were used in determining the pressure or static head on the line. One technique was a simple piezometer constructed of transparent plastic tube, of sufficient diameter to eliminate capillary action, fitted in one of the taps so that its end extended below the minimum anticipated sewage level in the pipe (Figure 60). The liquid rose in the tube until equilibrium was reached, and pressure was obtained by reading the vertical distance from the meniscus or liquid surface to the top of the fitting that held the tube in place. The elevation of each piezometer fitting was obtained and correlated with pipe elevations by field surveys. Since the specific gravity of sewage is near unity, the pressure in feet of water could be read directly at the required timed intervals.

The second technique used a section of six-inch diameter PVC pipe fitted onto the sewer line tap to form a float well. A spring-driven water-level recorder (Figure 61) with horizontal chart drum was then installed over the manhole and float well which provided a static head stage record versus time.

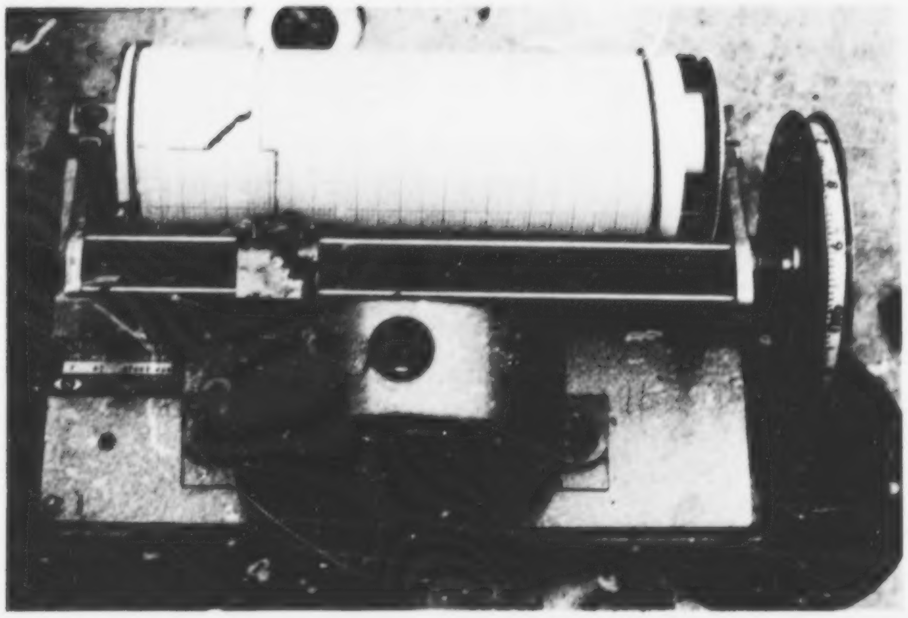


Figure 61. Water Level Recorder.

Sewage temperature was obtained by periodically observing a dial thermometer mounted through one of the taps. Fresh sewage samples were obtained through a hose bib fitted through the same tap as the thermometer.

A number of methods are available for determining flow measurement in pipes or conduits, including weirs, Parshall flumes, tracer materials, and formulas using depth-of-flow and pipe slope. Because of the surcharged flow condition and depth of the test section, it was decided that the use of a tracer material method would be most practical and economical.

This method of flow measurement requires that a tracer be injected into a stream at a continuous and uniform rate of determined concentration. The concentration of tracer material was then measured downstream from the point of injection after complete transverse mixing and uniform dispersion through the fluid had occurred.

Although many types of tracers are available for use, a dye, Rhodamine WT, was used in this study. This dye is essentially nontoxic, is rapidly dispersed in water, is visibly red in concentrations above 1.0 mg/1, and is not readily destroyed by chemical agents.

To determine the flow rate, a concentration of 4800 mg/l of Rhodamine WT was injected at a uniform rate of 0.1 gallon per minute in manhole "A" shown in Figure 59. A fluorometer equipped with an automatic recorder was used at the end of the 24-inch test section and is shown in Figures 62 and 63. The concentration of dye, proportioned to the flow rate in the sewer, can be calculated from the equation:

$Q = q \frac{C}{c}$ where Q = Flow rate of the stream.

q = Flow rate of dye injection in the stream at concentration C.

C = Dye concentration at injection.

c = Dye concentration at downstream measuring station.

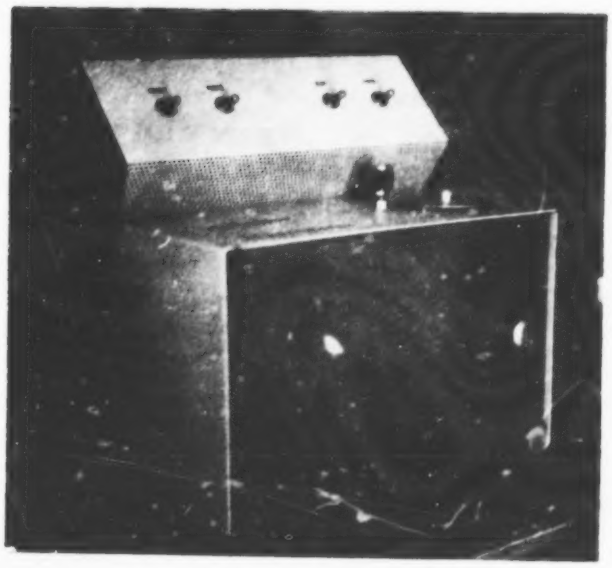


Figure 62. Fluorometer.

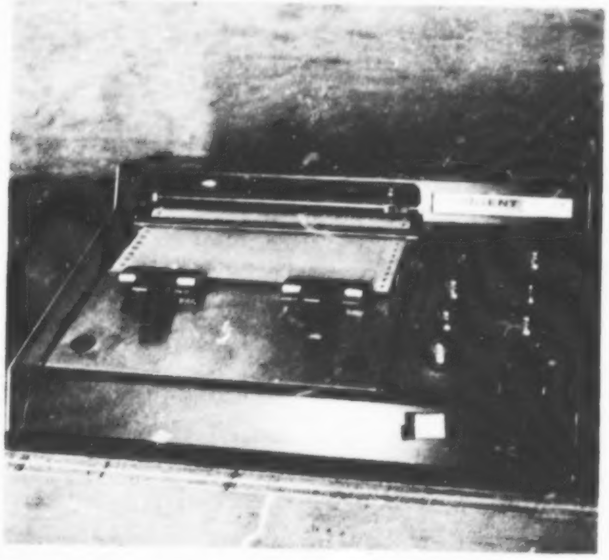


Figure 63. Fluorometer Recorder.

In order to obtain a continuous analysis of dye concentration, sewage was pumped from the sewer line through the fluorometer. A small centrifugal pump was used and fitted with a one-half inch diameter suction probe which extended through a tap in the pipe. While operating, suspended solids in the sewage clogged the probe inlet causing the pump to lose suction, prohibiting flow monitoring. Numerous techniques were tried to eliminate this operation difficulty; however, none provided a satisfactory solution to this problem. Because of the plumbing arrangement necessary to provide insertion and removal of the probe in the line and prevent leakage during high surcharges, screening of the inlet was not possible.

Also, during the periods the pump was not clogged, the dye concentrations recorded varied widely due to the passage of large suspended solids and small air bubbles through the fluorometer. Therefore, to determine the dye concentration, the flow-through monitoring mechanism on the fluorometer was abandoned in preference of individual sewage samples obtained manually with each sample analyzed separately in the fluorometer. This latter method proved to yield more reliable flow data, required less operation effort, and eliminated time gaps during which the flow could not be determined because of pump failure.

The concentration of dye in the sewage, c, was determined by corrections to the fluorometer dial reading. The normal background reading, previously determined for the sewage, was subtracted from the dial reading, which was then modified by a correction factor to compensate for temperature variance between the sewage sample and the calibration sample. Temperature correction curves for various dye tracers were supplied by the fluorometer manufacturer. This corrected reading was then converted to dye concentration by either entering the linear calibration curve of dial reading versus dye concentration, or by dividing the dial reading by the slope of the line given in the above plot. If the second method is used, the previous equation would appear as:

$$Q = q \frac{C}{\frac{R_f}{m}}$$

where R_f = the corrected fluorometer dial reading
m = the slope of the plot of R_f versus dye concentration curve.

The dye was mixed with water and stored in a 55-gallon drum, which was tapped and fitted with a valve and hose connections. A small positive-displacement pump with 3/8-inch piston diameter was used to pump the dye from this reservoir into the sewer line and is shown in Figure 64. The injection manhole cover was tapped and a 3/4-inch line fitted through the tap and connected to the dye pump. The end of the pipe was fitted with a 5-psi check valve which prevented the water level fluctuations from affecting the rate of dye discharge into the line.

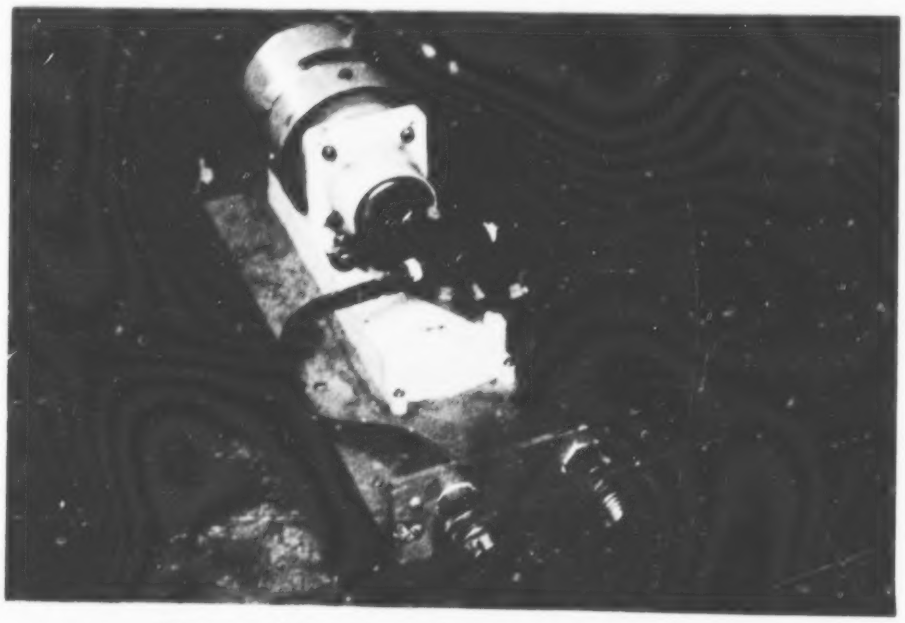


Figure 64. Dye Metering Pump.

A summary of the instrumentation installed at each existing and temporary manhole is listed in Table XVIII. Existing manholes are indicated by letters A, B, and C and temporary manholes by numerals 1, 2, 3, and 4 in Figure 59.

TABLE XVIII

TEST LINE MANHOLE INSTRUMENTATION

Manhole Number	Location	Instrumentation
1	Over 36-inch line 80' upstream from Sta. 0 + 00.	Piezometer read manually, temperature and sample.
A	Junction of 36- and 24-inch lines, Sta. 0 + 00.	Rhodamine WT and polymer injection point.
2	Over 24-inch line. Sta. 3 + 99.	Piezometer with level recorder.
3	Over 24-inch line. Sta. 6 + 43.	Piezometer read manually, temperature, and sample.
B	Over 24-inch line at 90° bend, Sta. 11 + 48	Piezometer with level recorder.
C	Over 24-inch line at 90° bend, Sta. 13 + 19.	Piezometer read manually.
4	Over 24-inch line at Sta. 15 + 63.	Piezometer with level recorder, fluorometer monitor for determining flow rate and sample.

Polymer Injection Equipment. The design and fabrication of a polymer injection device was accomplished during the program work, and consisted of two separate mobile units. One unit contained a cone bottom tank (Figure 65) with a capacity of 1143 gallons which provided a sealed

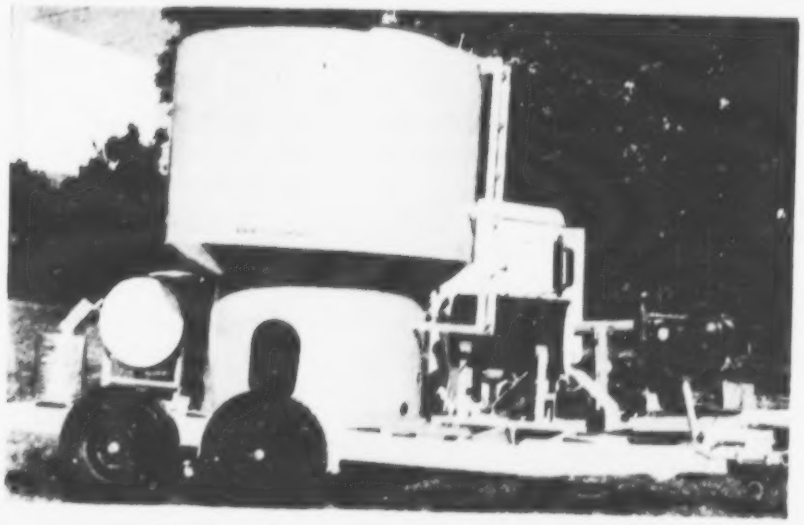


Figure 65. Slurry Mixing Tank.

container for mixing the polymer into a slurry and holding the polymer in suspension. The tank was equipped with piping arranged so that continuous recirculation of the nonsolvent, isopropyl alcohol, and gelling agent, klucel H, could be accomplished as the polymers were added, to form the slurry. This unit was also equipped with a 55-gallon drum of cellosolve for flushing the injection lines after each use to prevent the drying and clogging of the slurry in the lines. Adequate flushing of the eductor and discharge lines was necessary after each injection period.

The second unit actually contained the injection device (Figure 66) and consisted of a gasoline-driven, centrifugal sewage pump with a capacity of 250 gallons per minute, a six-inch eductor, a rotameter, a four-inch pipe and fittings, a flexible suction and flexible discharge line.

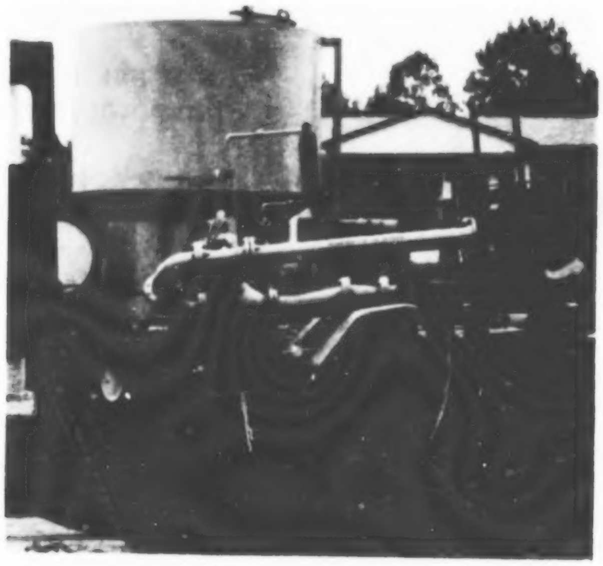


Figure 66. Injection Unit.

The injection unit was connected to the slurry tank by a one-inch line fitted with a one-inch magnetic flow meter, recorder and control valve to regulate the concentration of polymer released to the test line. The eductor was used to provide a vacuum on the tank discharge line which, coupled with the positive head of the tank, permitted the uniform flow of slurry from the tank to be regulated or proportioned by the one-inch control valve. In operation, the sewage was pumped from the sewer line through the eductor which discharges from the eductor nozzle at a high velocity and entrains the slurry from the tank suction line. The slurry and sewage were thoroughly mixed by the turbulence in the throat of the eductor and then discharged back into the sewer line. This flash mixing of slurry and sewage reduced the tendency of the highly water-soluble polymers to lump or agglomerate as when slowly added to water.

The slurry mixing tank and the injection unit are shown with parts identified in Figure 67.

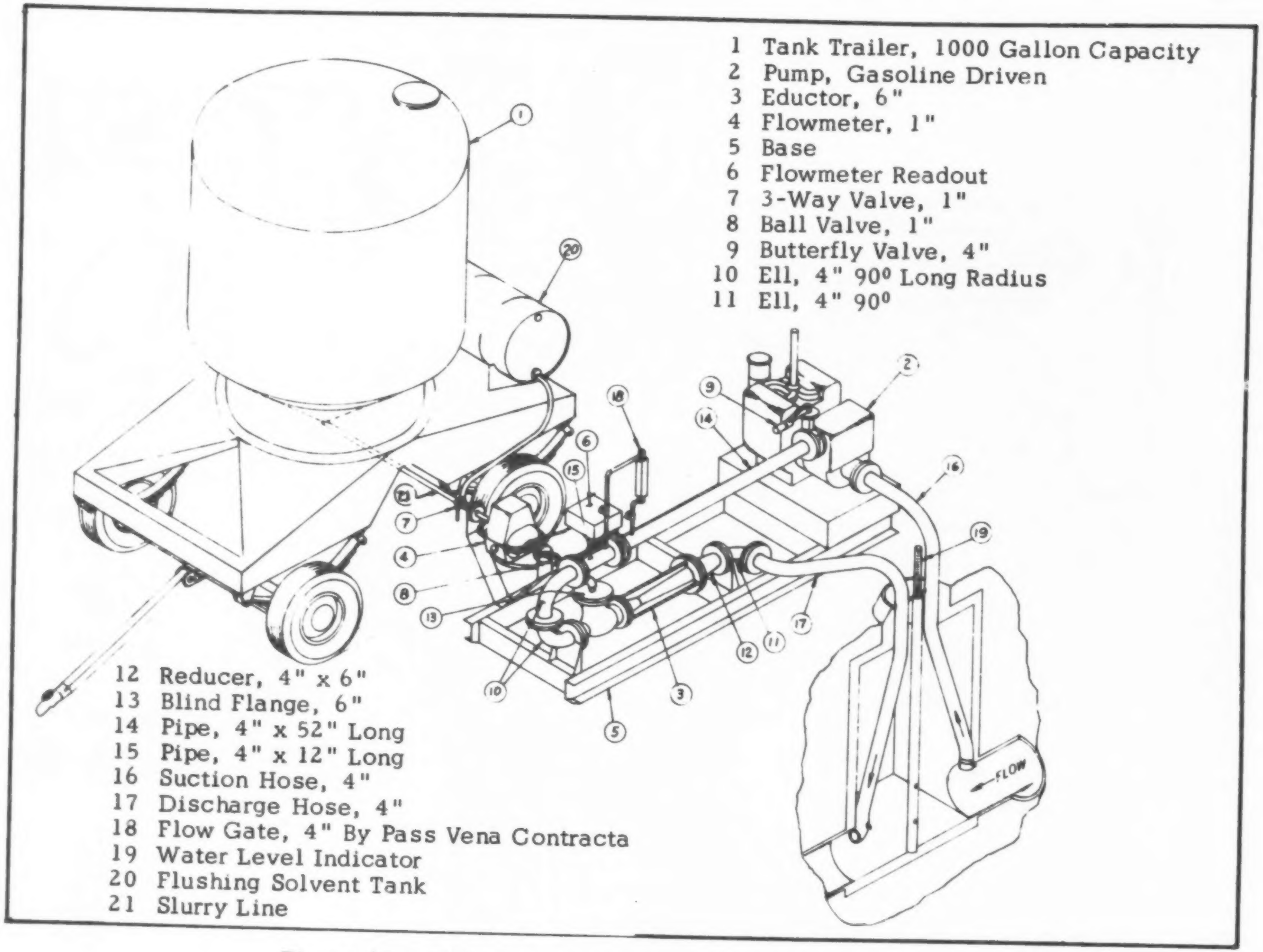

1 Tank Trailer, 1000 Gallon Capacity
2 Pump, Gasoline Driven
3 Eductor, 6"
4 Flowmeter, 1"
5 Base
6 Flowmeter Readout
7 3-Way Valve, 1"
8 Ball Valve, 1"
9 Butterfly Valve, 4"
10 Ell, 4" 90⁰ Long Radius
11 Ell, 4" 90⁰
12 Reducer, 4" x 6"
13 Blind Flange, 6"
14 Pipe, 4" x 52" Long
15 Pipe, 4" x 12" Long
16 Suction Hose, 4"
17 Discharge Hose, 4"
18 Flow Gate, 4" By Pass Vena Contracta
19 Water Level Indicator
20 Flushing Solvent Tank
21 Slurry Line
FLOW

Figure 67. Field Injection System With List of Parts.

The injection manhole cover was modified to provide connections for the suction and discharge lines of the sewage pump and the injector line (Figure 68). Inside the manhole, four-inch PVC pipe was installed between the pressure manhole cover and the flow line of the sewer pipe. A pressure manhole cover was necessary because of the magnitude of surcharge on the line during peak flows. The cover was modified by cutting holes and welding flanged adaptors to the cover. Butterfly valves and quick-disconnect couplings were attached to the adaptors. The two units and operations truck are shown on location in Figure 69.

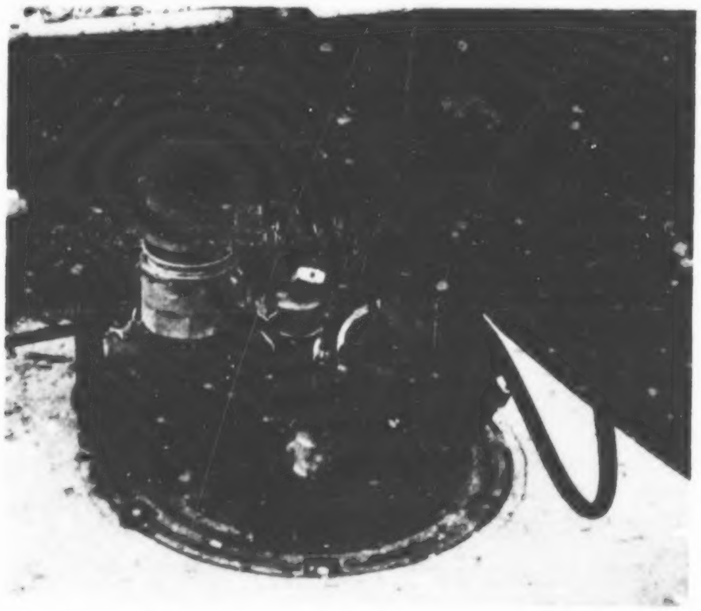


Figure 68. Injection Manhole Cover at Manhole "A"

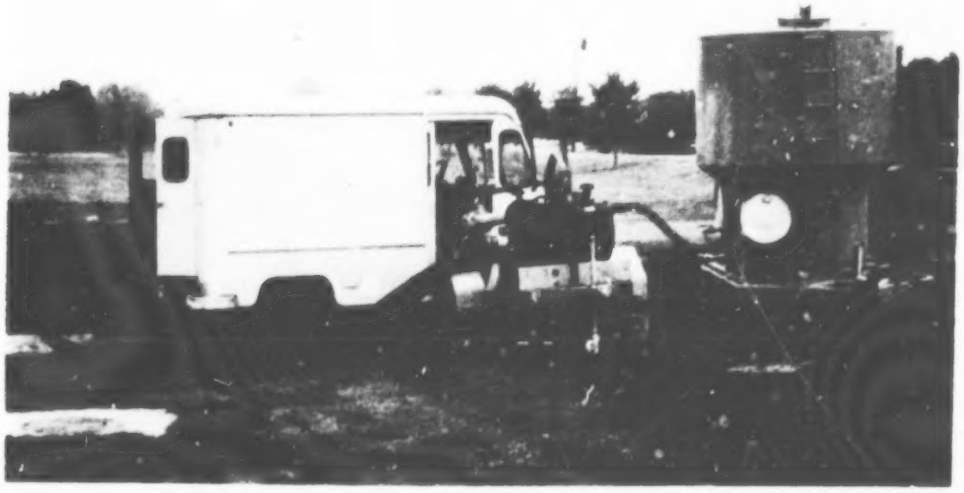


Figure 69. Units in Operation at Manhole "A".

Slurry Composition. As indicated, the polyethylene oxides (WSR-301 and Polyox Coagulant-701) are water soluble; however, dissolving the polymers requires thorough dispersion of the individual resin particles during the initial contact with water. As the polymer surfaces begin to absorb water, a cohesive mass is formed that will dissolve only after prolonged agitation.

Since adequate polymer dispersion is necessary for complete and rapid dissolving in water, a method is required for injecting the polymer into the solvent or water that will keep the polymers in suspension. A nonsolvent that has been gelled was found to be an effective technique for injecting the polymers into water. Anhydrous isopropyl alcohol gelled with klucel H formed the nonsolvent gel used in the field evaluation work on the 24-inch surcharged sewer.

The technique of dispersing polymer in a slurry can be accomplished readily and the slurry is stable for long periods of time (if agitated daily), which allows use as need occurs. When injected into water, the polymer slurries form aqueous systems quickly with a minimum of mixing or agitation. A complete discussion of the technique used in mixing the slurries is given in Appendix D.

The slurry used in the 24-inch sewer line demonstration consisted of 69.25 percent isopropyl alcohol (nonsolvent), 0.75 percent klucel H (gelling agent), and 30 percent polymer. The current (April, 1969) unit costs of slurry components in quantities less than 5,000 pounds are: isopropyl alcohol, $0.69 per gallon; klucel H, $1.30 per pound; WSR-301 polymer, $0.80 per pound; or Polyox Coagulant-701 polymer, $1.45 per pound. The cost of preparing a slurry of WSR-301 is $216.89 per 100 gallons. This material cost is increased by $144.50 per 100 gallons if Polyox Coagulant-701 polymer is substituted for the WSR-301 polymer. Table XIX indicates the material cost in dollars per hour for injecting the slurry at 50 mg/l and 100 mg/l polymer concentration at the indicated wastewater flow rates.

TABLE XIX

POLYMER INJECTION COSTS -- DOLLARS PER HOUR

Flow		WSR-301		Polyox Coagulant-701	
CFS	MGD	50mg/l $ / hr	100mg/l $ / hr	50 mg/l $ / hr	100mg/l $ / hr
1.12	0.72	13.32	26.64	21.56	43.12
2.23	1.44	26.64	53.28	43.12	86.24
5.57	3.60	66.60	133.20	107.82	215.64
11.14	7.20	133.20	266.40	215.64	431.28
16.71	10.80	199.80	399.60	323.46	646.92
22.28	14.40	266.40	532.80	431.28	862.56
27.85	18.00	333.00	666.00	539.10	1078.20
33.42	21.60	399.60	799.20	646.92	1293.84

If the materials are purchased in quantities of greater than 20,000 pounds, the WSR-301 slurry cost can be reduced by 20 percent and the Polyox Coagulant-701 slurry cost can be reduced by 15 percent.

Instrument Calibration. Prior to beginning full-scale testing of the friction-reduction process, calibration of the fluorometer, tracer metering pump, and level recorders was necessary.

The fluorometer, G. K. Turner Model 111, was calibrated by using Rhodamine WT, distilled water, and sewage obtained from the 24-inch test line. To convert the relative fluorometer readings to concentrations of a fluorescent solute, the instrument had to be calibrated by using prepared solutions of known dye concentration and determining the relation of fluorometer dial reading, R_f value, to the dye concentration. A known concentration of Rhodamine WT was diluted in distilled water at a temperature of 72°F (base temperature). Dial readings were observed for the different concentrations of dye and a plot of the fluorometer (R_f) versus concentration was developed.

Before each field test was started, the fluorometer dial readings for sewage without added tracer was monitored to determine the natural fluorescence of the sewage (background readings). Corrections, based on the background readings and the sewage temperature, were applied to the test data obtained. Temperatures above the base value create dial readings higher than actual while temperatures lower than the base cause dial readings lower than actual.

The calculation of flow rate when using the tracer method require the addition of tracer to the wastewater at a uniform and constant rate. To obtain this, a small positive-displacement pump was used to regulate the flow of dye at 0.1 gallon per minute. The flow rate was calibrated by determining the volume of dye delivered by the pump during a timed period.

The magnetic flow meter on the slurry injection equipment was calibrated by preparing a chart of discharge rate versus polymer concentration so that the discharge valve could be adjusted to provide the correct dosage by reading the magnetic flow meter.

Calibration of the Stevens (Type F) water-level recorders consisted of setting the recorder with reference to the bottom of a stilling well of known elevation with respect to the flow line elevation of the sewer at the installation location.

Demonstration Test Procedure. The line selected for the full-scale demonstration test was surcharged almost daily, eliminating the need for predicting periods of peak flow based on rainfall duration and intensity.

The initial step in conducting a test run was the preparation of slurry containing the friction-reduction additive. After pumping the nonsolvent into the tank unit of the injector, the gelling agent was slowly added and thoroughly mixed with the nonsolvent by recirculating the two components through the tank with a positive-displacement pump for a period of approximately 12 hours to insure even dispersement. After the formation of a gel, polymer was slowly added to the gel while being agitated. Various refinements in mixing the polymer slurry are discussed in Appendix D.

The formation of a slurry was obtained in one to two hours, depending on the batch size. Test batches of over 500 gallons were most difficult to prepare. To facilitate the determination of the rate of slurry discharge from the tank through the magnetic flow meter, a small quantity of potassium acetate (0.077 percent or about 1.1 pounds per 200 gallons of slurry) were added to the slurry to increase the conductivity. In general, the mixing procedure usually required about 14 hours of preparation prior to beginning the test; however, it should be noted that this time was reduced by four to six hours when the procedures described in Appendix D were used. The slurry was stable, if agitated periodically, and batches can be made and stored until needed as an operating practice.

Prior to beginning the injection of a friction-reducing polymer, flow conditions in the 24-inch test line were analyzed to determine if the static head on the line was increasing or decreasing at manhole number 1 (because of increasing or decreasing flow), and if each observation manhole in the test section was surcharged, but not an excessive amount (overflowing top of manhole). If the test parameters were met, a continuous sample of the wastewater was pumped from the test line through the fluorometer or individual samples collected and analyzed separately for normal fluorescence determination as required for calibration. Samples were taken from manhole number 4 for analysis of dissolved oxygen, total solids, settleable solids, pH, and specific conductance.

While the preparatory tasks were being accomplished, the slurry was transported to the test site, and the injector and tank units set in position at manhole A. The 4-inch flexible suction and discharge lines were connected to the quick disconnect couplings on the modified pressure type manhole cover and on the injector unit. The tank unit was connected to the injector unit by flexible hose and the pump engine started. The slurry could then be injected into the line when desired by simply opening the butterfly control valve on the tank discharge line.

Prior to actual polymer injection, the tracer dye was pumped into the line and the sewage flow rate monitored. Also, water level readings were started approximately 30 minutes prior to injection, and the ambient and fluid temperatures were noted at the various manholes.

Based on the recorded flow rate in the sewer pipe and the desired polymer concentration, the flow rate of slurry from the tank was controlled by the butterfly valve as monitored by the magnetic flow meter.

During the first 15 minutes of slurry injection, piezometer readings were taken at 1-minute intervals so that the initial head reduction could be detected. After this period, piezometer readings were taken at maximum intervals of 15 minutes with the time each reading was taken being recorded at each manhole. After injecting for 30 minutes and 60 minutes, grab sewage samples were taken from manholes 1 and 4, and composited for each sample location.

The slurry was injected until the surcharge was eliminated by reducing the frictional losses sufficiently to carry all of the wastewater within the pipe. At the termination of polymer injection, piezometer readings were taken at 1-minute intervals for 15 minutes to detect the initial increase in head, and followed by readings taken at 15-minute intervals until the flow returned to or near the original surcharged condition. At this time, a final sample was taken from manhole number 4, completing the demonstration test procedure.

Test Results and Analysis. The purpose of full-scale sewer line testing was to demonstrate the similarity of flow phenomena and to verify the results obtained in the six-inch model sewer line tests. As previously mentioned, two polymers were tested, WSR-301 and Polyox Coagulant-701 in a gel of isopropyl alcohol and klucel H. The slurry contained 30-percent polymer (by weight) and was injected into the sewer line at concentrations of polymer varying between 35 and 100 mg/l. After running one test to refine test procedures, four tests were conducted with each polymer with varying results and data reliability.

Results from these tests confirm the results obtained from the small-scale test model in that the frictional resistance to flow can be decreased to an extent that the surcharge can be eliminated.

A typical week-day hydrograph of the flow depth in the line at injection manhole 1 is given in Figure 70. Tests were conducted during the last week of August, the month of September and the first week of October; the period during the year when rainfall and infiltration of ground water is minimal in the Dallas, Texas, area. During wet periods, excessive infiltration caused overflow of the monitoring manholes and prohibited the collection of test data.

Figure 70 is the plot of the sewer hydrographs obtained on the day WSR-301 was injected into the line at approximately 80 mg/l concentration. The pressure head on the line was reduced approximately four feet throughout the test section during the one-hour injection period. It is apparent in Figure 70 that the polymer injection was started as the flow was beginning to decrease (indicated by the decrease in surcharge on the line). As a result, the polymer reduced the energy required to drive the flow which was initially 6,500 gpm. This flow rate was increased during the injection period but only slightly since the hydraulic gradient decreased continuously as the surcharge dropped. An explanation of the effects of polymers on a gravity flow system is given in Appendix B.

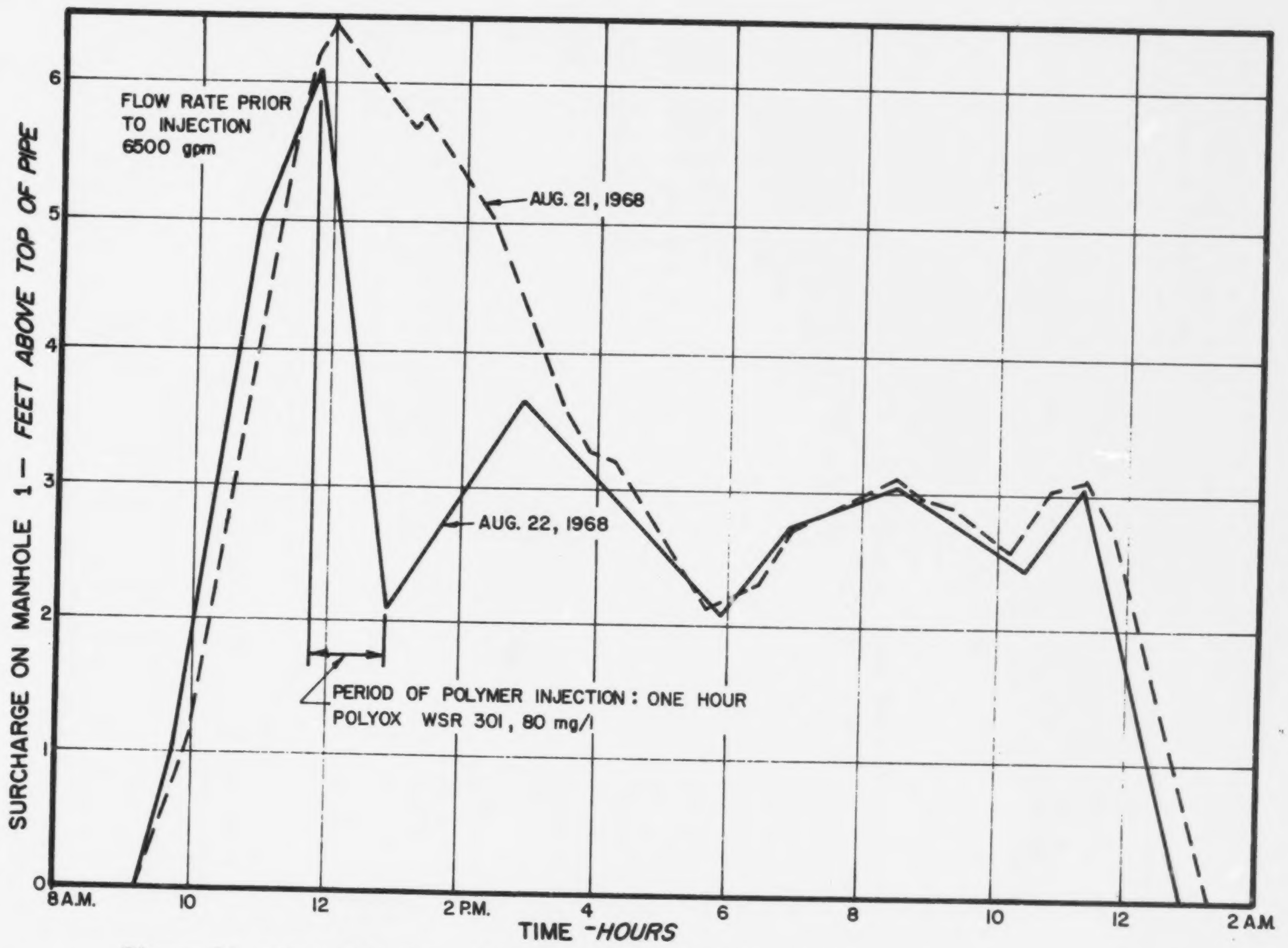


Figure 70. Head Reduction Obtained Using 80 mg/1 of WSR-301.

Similar hydrographs for each monitoring manhole are shown in Figures 71 and 72. It should be observed that at each manhole below the injection point an increase in head occurred shortly after the additive was injected and proceeded down the line. This increase in head was caused by a transient flow phenomenon resulting from reduced boundary shear stresses or frictional losses in the sewage. When the flow volume in the 24-inch pipe adjusted to the new flow rate, the head dropped uniformly along the pipe.

In Figure 71, polymer injection was again started as the flow reached a peak. As a result, the flow rate was only slightly increased because of the decrease in both the hydraulic gradient and the volume of wastewater to be carried by the pipe. Similar results were obtained for the tests presented in Figure 70, however, in Figure 72, polymer was injected while the volume of flow was increasing since the flow history of the line indicated that peak flow usually occurred between 11:30 a.m. and 12 noon on week days. As a result of injecting under this condition, a flow rate increase was obtained in addition to a decrease in the surcharge or static head. This flow increase was a result of the reduction in the frictional resistance to flow provided by the polymers and the continued increase in volume of wastewater to be carried in the pipe.

In each of the tests, injection of polymer was stopped when the desired results were obtained (reduction of the head on the line to eliminate a surcharged condition or a pollution source).

Analyses of sewage grab samples were made so that the characteristics of the sewage could be determined, should the effectiveness of the friction-reduction additive be considerably less than anticipated (see Section III of this report for effects of sewage on polymers). In general, the two additives were as effective as anticipated and only dissolved oxygen, total solids, suspended solids, pH, specific conductance, and temperature tests were made in accordance with the procedures detailed in the Twelfth Edition of Standard Methods for the Examination of Water and Wastewater. Table XX presents the results obtained for test runs using WSR-301 and Polyox Coagulant-701.

As a result of full-scale tests on the 24-inch diameter sanitary sewer line, the elimination of surcharged flow conditions was possible by injecting a slurry containing polymer which reduced shear stresses within the fluid and caused a decrease in the frictional resistance to flow. The reduction of frictional losses in the test section decreased the static head required to drive the inordinate flow, resulting in the head drops observed in the piezometers.

These same flow phenomena were obtained in the six-inch line, tests conducted in the earlier phases of this program. In these tests, however, a constant flow rate was maintained and the friction-reduction effects of the polymer were observed by reductions in static head on the line. Since constant flow conditions were not obtainable in the field test, the effects of the polymer slurry were observed by both static head reduction and slight flow increases, as described in Appendix B.

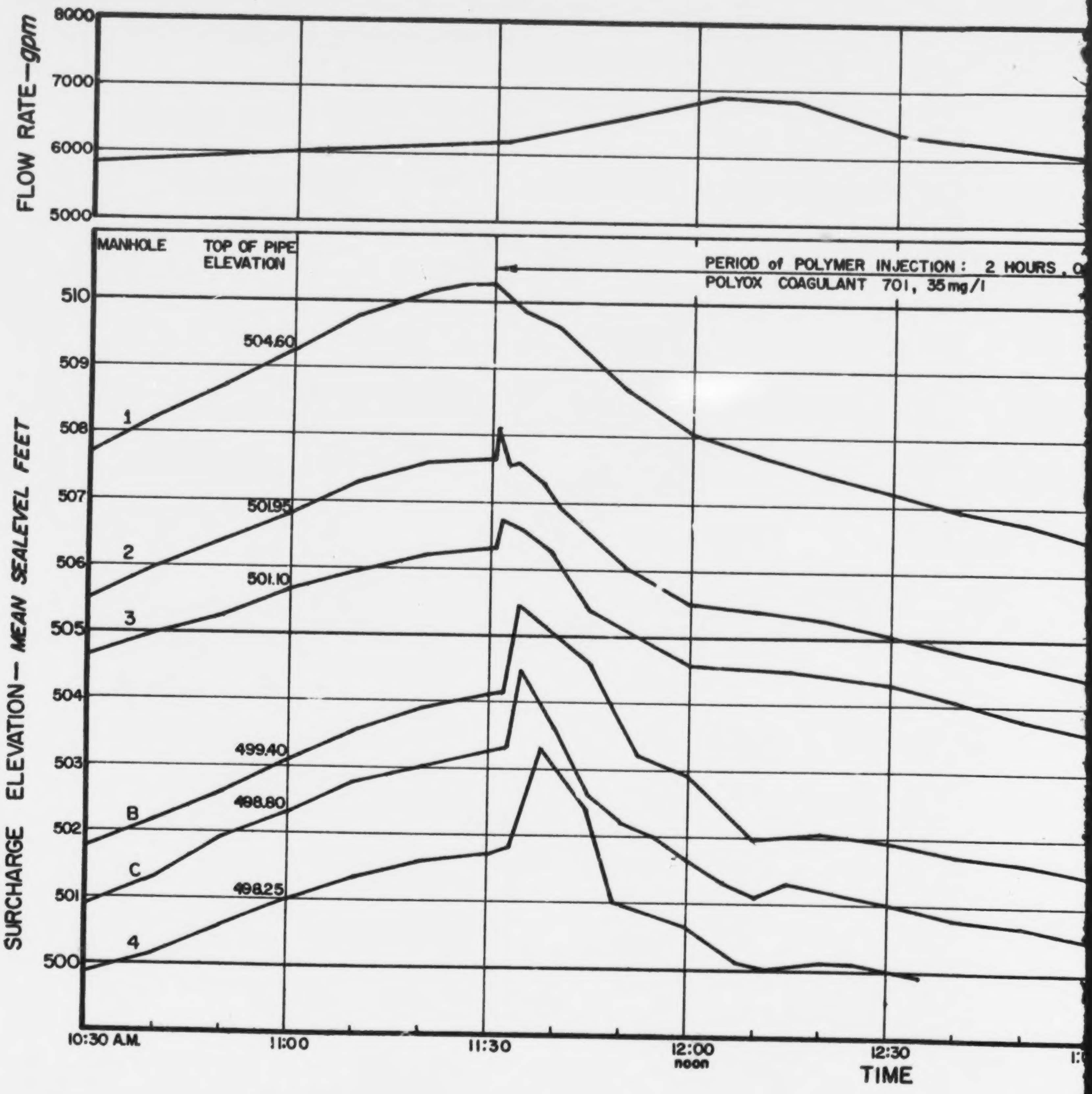
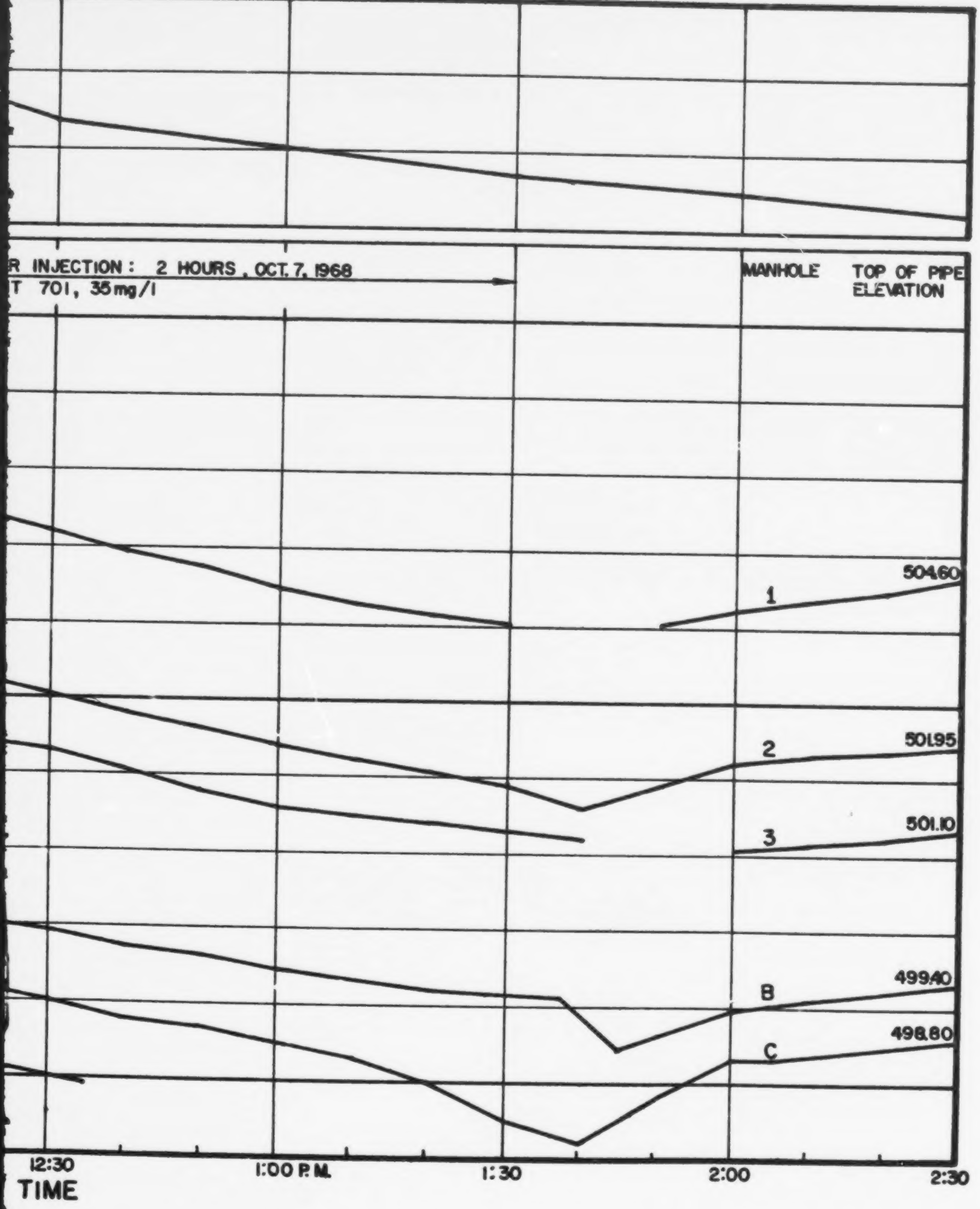


Figure 71. Hydrograph of Flow and Surcharge of Monitoring Manholes Before, During, and Afte

A



fore, During, and After Injecting Polyox Coagulant-701.

B

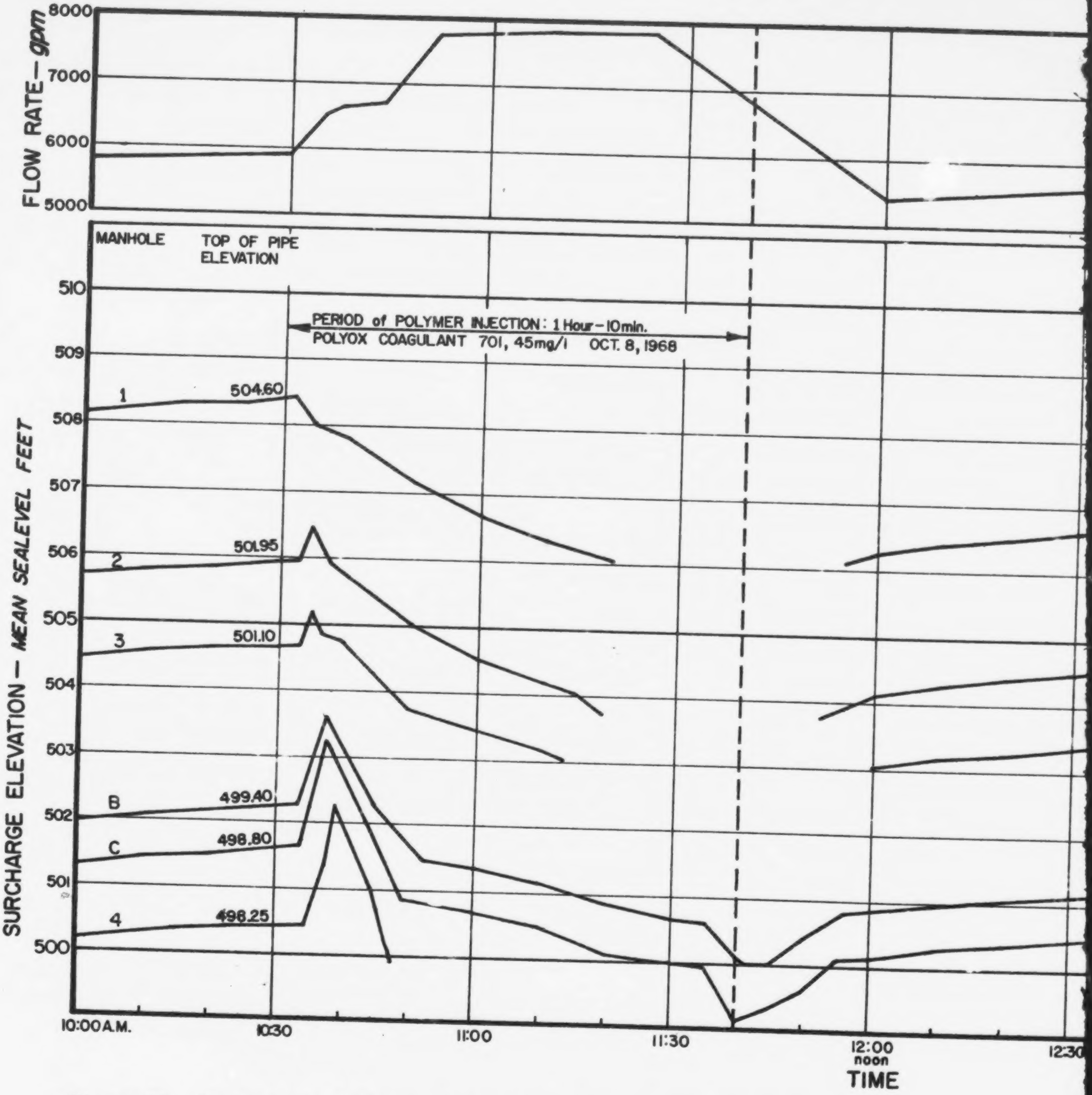
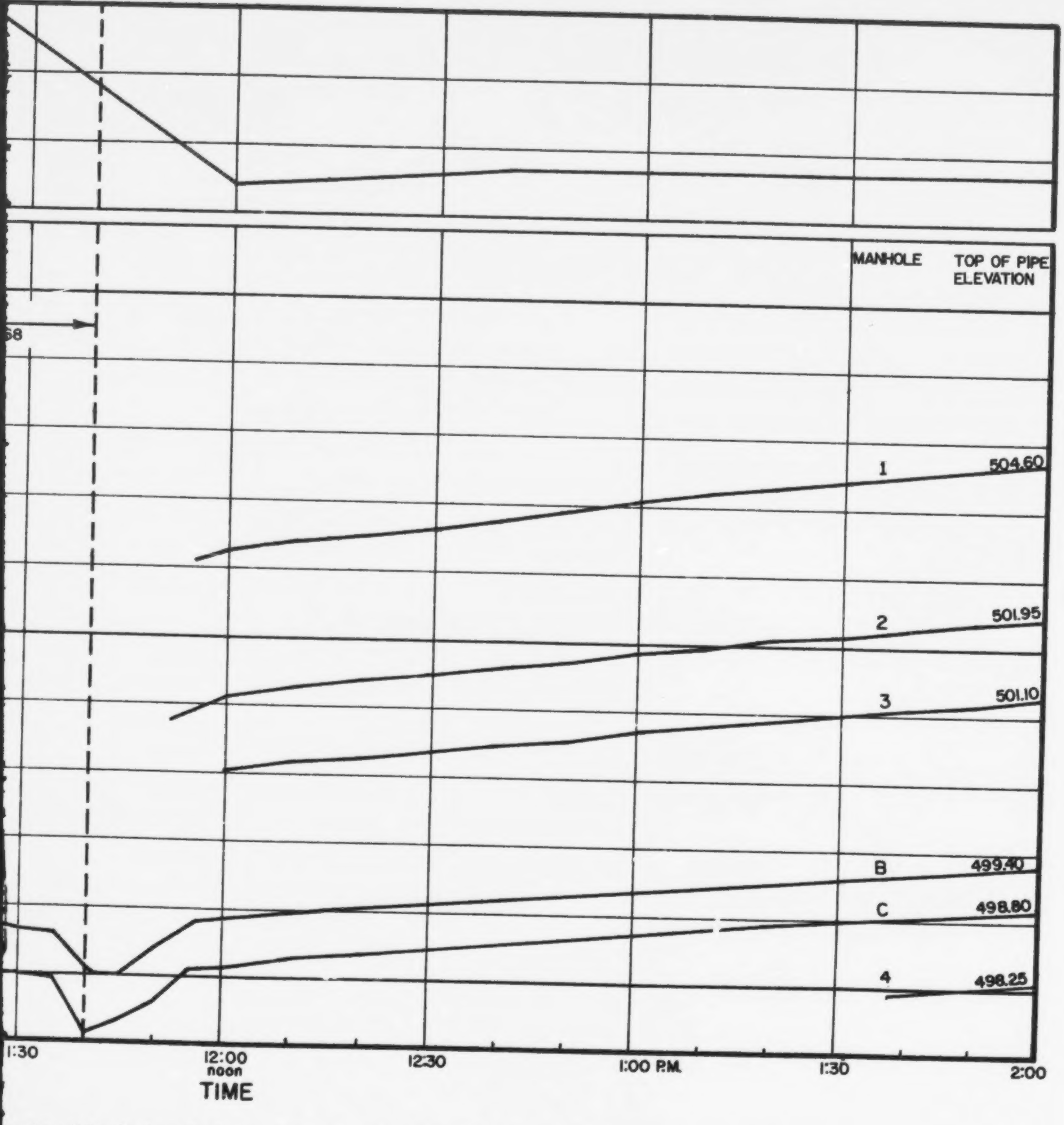


Figure 72. Hydrograph of Flow and Surcharge of Monitoring Manholes Before, During, and Aft

A



toring Manholes Before, During, and After Injecting Polyox Coagulant-701.

B

TABLE XX

SEWAGE SAMPLE ANALYSES FOR 24-INCH SEWER LINE TEST RUNS

Date	Polymer Concentration (mg/l)	Temperature (^{0}F)	DO (mg/l)	Total Solids (mg/l)	Suspended Solids (mg/l)	pH	Specific Conductance (μ mho)
POLYOX WSR-301							
Aug. 22, 1968	0	86	6.0	897	172	7.7	1240
Aug. 22, 1968	0	87	4.0	789	146	6.8	1020
Aug. 22, 1968	0	86	7.2	919	158	7.2	1630
Aug. 22, 1968	80	86	5.8	957	122	7.3	1041
Aug. 22, 1968	80	87	7.0	1133	102	8.4	834
Aug. 22, 1968	0	87	6.4	851	131	7.0	1017
Aug. 27, 1968	0	86	7.2	844	228	6.5	953
Aug. 27, 1968	75	87	9.0	1178	226	7.0	872
Sept. 3, 1968	0	85	6.8	912	124	7.4	962
Sept. 3, 1968	40	85	6.8	1258	216	8.0	862
Sept. 4, 1968	0	84	8.6	755	134	8.4	1513
Sept. 4, 1968	100	84	8.8	1376	160	9.1	1103
POLYOX COAGULANT-701							
Sept. 20, 1968	0	80	Data Not Obtained	840	112	7.2	2510
Sept. 20, 1968	50	82		980	154	7.1	2660
Sept. 20, 1968	50	82		1120	185	7.2	720
Sept. 20, 1968	0	85		885	108	6.9	1230
Sept. 27, 1968	0	82		1421	290	6.9	1050
Sept. 27, 1968	80	82		1938	386	6.9	880
Sept. 27, 1968	80	82		2168	415	6.8	680
Sept. 27, 1968	0	85		985	195	7.3	1100
Oct. 7, 1968	0	78		620	148	6.6	790
Oct. 7, 1968	0	79		780	196	6.8	825
Oct. 7, 1968	35	80		910	115	6.7	925
Oct. 7, 1968	35	80		1163	230	6.8	689
Oct. 7, 1968	0	81		852	178	7.4	768
Oct. 7, 1968	0	80		1160	264	7.1	510

TABLE XX

SEWAGE SAMPLE ANALYSES FOR 24-INCH SEWER LINE TEST RUNS (Continued)

Date	Polymer Concentration (mg/l)	Temperature (°F)	DO (mg/l)	Total Solids (mg/l)	Suspended Solids (mg/l)	pH	Specific Conductance (μ mho)
Oct. 8, 1968	0	79	Data Not Obtained	930	164	7.0	1125
Oct. 8, 1968	0	80		1133	195	7.2	1060
Oct. 8, 1968	45	79		860	132	7.0	739
Oct. 8, 1968	45	80		980	145	7.1	770
Oct. 8, 1968	0	80		760	217	8.5	1050

During the various test runs, slurry injection rates, using WSR-301 and Polyox Coagulant-701, were operated between 35 and 100 milligrams per liter as shown in Table XXI. Each concentration used resulted in a reduction in surcharge, with the smaller concentrations requiring

TABLE XXI

RESULTS OF 24-INCH SEWER LINE TEST RUNS

Time	Flow Rate (gpm)	Polymer Concentration (mg/l)	Surcharge Above Top of Pipe in Feet at Manhole					
			1	2	3	B	C	4
August 22, 1968 - Polyox WSR-301								
11:56 AM	6500	Start Inj.	6.95	6.80	Data Not Obtained	Data Not Obtained	Data Not Obtained	4.05
12:00 N	6500	80	6.85	6.70				4.20
12:15 PM	6200	Approx. 80	6.30	6.20				8.25
12:30	#	Approx. 80	5.35	5.20				3.75
12:45	#	Approx. 80	3.85	3.75				2.45
12:53	#	Stop Inj.	3.25	3.15				1.50
1:00		0	3.40	3.00				# #
1:15	#	0	3.60	3.65				1.55
1:30	#	0	3.85	3.90				1.70

TABLE XXI (Continued)

RESULTS OF 24-INCH SEWER LINE TEST RUNS

Time	Flow Rate (gpm)	Polymer Concentration (mg/l)	Surcharge Above Top of Pipe in Feet at Manhole					
			1	2	3	B	C	4
August 27, 1968 - Polyox WSR-301								
2:00 PM	6000	Start Inj.	6.05	6.45	Data Not Obtained	Data Not Obtained	Data Not Obtained	3.40
2:15	6500	75	5.10	5.35				3.55
2:30	6000	75	4.15	4.35				3.05
2:45	5650	75	3.45	3.70				2.50
3:00	#	Approx. 75	2.90	3.40				2.20
3:15	#	75	2.30	2.80				1.75
3:30	#	75	1.85	2.40				# #
3:45	#	Stop Inj.	1.70	1.80				# #
September 3, 1968 - Polyox WSR-301								
11:15 AM	5600	Start Inj.	5.75	5.95	-	Data Not Obtained	Data Not Obtained	-
11:30	6300	40	4.80	4.95	4.80			3.40
11:45	6700	40	3.65	3.85	3.80			2.25
12:00	6200	40	2.95	3.30	3.05			1.50
12:15 PM	#	Approx. 40	2.25	2.55	2.55			# #
12:30	#	40	1.75	1.95	2.05			# #
12:40	#	Stop Inj.	1.45	1.80	1.75			# #
September 4, 1968 - Polyox WSR-301								
9:45	5700	0	3.70	-	Data Not Obtained	Data Not Obtained	Data Not Obtained	-
10:00	5900	Start Inj.	3.95	4.15				-
10:10	8500	100	3.40	3.80				3.40
10:18	8500	100	2.60	2.70				1.80
10:28	6400	Stop Inj.	2.10	1.65				# #
10:40	#	0	2.45	2.60				# #
10:50	#	0	3.05	-				# #
11:00	#	0	3.70	-				-
11:10	#	0	4.40	-				-
September 20, 1968 - Polyox Coagulant-701								
10:20 AM	6100	0	6.25		5.65	4.80	4.40	3.50
10:35	6200	0	6.40		5.70	5.05	4.70	3.75

TABLE XXI (Continued)

RESULTS OF 24-INCH SEWER LINE TEST RUNS

Time	Flow Rate (gpm)	Polymer Concentration (mg/l)	Surcharge Above Top of Pipe in Feet at Manhole					
			1	2	3	B	C	4
September 20, 1968 - Polyox Coagulant-701 (Continued)								
10:50	6200	Start Inj.	6.80	Data Not Obtained	6.15	5.20	5.00	3.90
11:00	6450	50	6.20		6.05	6.70	5.75	5.90
11:15	7100	45	4.85		4.55	4.90	4.30	3.55
11:30	7000	60	3.50		3.45	3.60	3.15	2.65
11:45	6400	50	2.60		2.85	2.35	2.15	# #
12 N	#	Approx. 50	1.90		2.25	1.85	1.55	# #
12:15 PM	#	Stop Inj.	1.80		# #	0.70	0.30	# #
12:30	#	0	2.30		# #	1.75	1.60	# #
12:45	#	0	2.80		2.85	2.10	1.90	# #
1:00	#	0	3.25		3.22	2.25	2.20	1.75
1:15	#	0	3.75		3.60	2.55	2.50	1.85
1:30	5700	0	4.00		3.85	2.95	2.85	2.15
1:45	5750	0	4.20		3.95	3.10	2.90	2.25
2:00	5900	0	4.35		4.00	3.20	3.00	2.35
September 27, 1968 - Polyox Coagulant-701								
10:00 AM	6100	0	4.95	Data Not Obtained	4.35	4.05	3.60	Data Not Obtained
10:15	6100	0	5.30		4.60	4.30	3.80	
10:30	6150	0	5.50		4.80	4.55	4.00	
10:40	6150	Start Inj.	5.60		4.95	4.65	4.15	
10:50	6700	80	4.35		5.50	6.00	5.70	
11:00	7300	75	2.90		3.05	2.45	2.30	
11:10	7500	80	2.20		2.70	2.10	1.90	
11:20	7600	Stop Inj.	1.45		1.95	1.35	1.35	
11:30	#	0	2.00		# #	1.00	0.60	
11:45	#	0	2.55		# #	2.20	1.90	
12:00 N	#	0	2.90		2.85	2.35	1.95	
12:15	#	0	3.20		3.10	2.50	2.15	
12:30	#	0	3.25		3.25	2.60	2.25	
12:45	#	0	3.25		3.25	2.60	2.30	
1:00	5650	0	3.20		3.20	2.55	2.30	
October 7, 1968 - Polyox Coagulant-701								
10:30	5850	0	3.10	3.55	3.45	2.35	2.10	1.65
10:45	5950	0	3.90	4.20	4.00	2.95	2.90	2.15

TABLE XXI (Continued)

RESULTS OF 24-INCH SEWER LINE TEST RUNS

Time	Flow Rate (gpm)	Polymer Concentration (mg/l)	Surcharge Above Top of Pipe in Feet at Manhole					
			1	2	3	B	C	4
October 7, 1968 - Polyox Coagulant-701 (Continued)								
11:00	6050	0	4.65	4.85	4.50	3.70	3.50	2.75
11:15	6100	0	5.35	5.45	4.95	4.35	4.10	3.25
11:30	6200	Start Inj.	5.60	5.70	5.20	4.70	4.40	3.50
11:45	6500	35	4.45	4.30	4.25	5.20	3.80	4.15
12 N	6850	30	3.45	3.55	3.45	3.50	2.85	2.40
12:15 PM	6850	35	3.00	3.40	3.35	2.70	2.45	1.85
12:30	6300	35	2.55	3.10	3.15	2.50	2.20	1.75
12:45	6150	40	2.25	2.75	2.80	2.30	2.00	# #
1:00	6000	35	1.85	2.45	2.50	2.15	1.70	# #
1:15	5850	35	1.60	2.15	2.35	2.00	1.35	# #
1:30	5700	Stop Inj.	1.45	1.95	2.20	1.80	0.70	# #
1:45	5600	0	# #	1.80	# #	1.05	0.70	# #
2:00	5500	0	1.65	2.25	1.95	1.55	1.40	# #
2:15	5400	0	1.85	2.40	2.10	1.75	1.60	# #
2:30	5250	0	2.05	2.50	2.25	1.90	1.70	# #
October 8, 1968 - Polyox Coagulant-701								
10:00 AM	5800	0	3.55	3.75	3.35	2.60	2.55	1.95
10:15	5850	0	3.70	3.90	3.50	2.70	2.70	2.10
10:30	5900	Start Inj.	3.80	4.00	3.55	2.85	2.80	2.20
10:45	6700	45	2.85	3.45	3.00	2.85	2.90	2.75
11:00	7800	40	2.05	2.55	2.35	1.95	1.90	# #
11:15	7850	50	1.55	2.10	1.85	1.60	1.45	# #
11:30	7500	45	# #	# #	# #	1.30	1.20	# #
11:40	6750	Stop Inj.	# #	# #	# #	0.70	0.30	# #
12 N	5350	0	1.65	2.15	1.95	1.45	1.35	# #
12:15 PM	5450	0	1.85	2.35	2.10	1.60	1.55	# #
12:30	5600	0	2.00	2.55	2.25	1.70	1.60	# #
12:45	5700	0	2.20	2.70	2.40	1.80	1.80	# #
1:00	5700	0	2.45	2.90	2.60	1.95	1.95	# #
1:15	5700	0	2.65	3.10	2.75	2.05	2.05	# #
1:30	5700	0	2.80	3.20	2.90	2.20	2.15	# #
1:45	5700	0	2.95	3.35	3.05	2.30	2.25	1.70
2:00	5700	0	3.10	3.45	3.15	2.45	2.30	1.80

# Not able to obtain sample for fluorometer because of equipment failure.
# # Surcharge level below sewer line tap.

longer time periods to develop the same pressure head drop that was obtained with the higher polymer concentration. From such head drop observations, it would be reasonable to conclude that extreme surcharged conditions could be eliminated more rapidly by increasing the initial polymer concentration rate or varying the polymer concentration upward to an amount that would provide the relief desired. Both polymers were effective in obtaining the desired head reduction, although Polyox Coagulant-701 provided a more rapid head reduction for the same polymer concentration.

The mobil injector unit and tank were operated efficiently by one person, although with modifications the equipment could be made to operate automatically.

Wastewater Treatment Plant Tests

Description of Wastewater Treatment Plant. The selection of a treatment plant as a possible test site to measure the effects of polymer additives on the treatment processes, was conducted by investigating the characteristics of several wastewater treatment plants of cities in the Dallas Metropolitan Area. Inspection of the treatment plants was conducted to determine how well each plant would meet the following criteria for a good test site:

> The treatment plant had to consist of at least a primary clarification unit, a filtration unit, a digester, and a sludge drying bed.
>
> The treatment plant should be suitable for installation of temporary flow measuring instrumentation and injection equipment, and for obtaining sewage samples for laboratory analysis.
>
> The plant should be easily accessible to injection equipment.

Treatment plants considered for the field test site were in the cities of Garland, Plano, Richardson, Carrollton, Mesquite, and Lewisville, Texas. A summary of the locations investigated along with pertinent information is shown in Table XXII.

Investigation of the locations indicated that the Carrollton and Lewisville treatment plants would require the least amount of polymer to perform the tests, because the daily flow rate was the lowest of the plants. In addition, it was determined that the Lewisville plant would require the least amount of instrumentation.

Using this as a basis, it was recommended that either the Carrollton or the Lewisville treatment plant be selected as the test site to measure the effect of chosen polymer additives on the treatment process, however,

TABLE XXII

INITIAL TEST SITES INVESTIGATED

Location City	Available	Flow (mgd)	Influent Line Size	Instruments Already In Place	Cost of Additional Instruments Required	Estimated Polymer Cost	Travel Distance to Plant Miles
Carrollton	yes	0.8	10"	-------	$12,334	$ 5,446	10
Garland	yes	10.0	48"	Parshall Flume	27,000+	14,630	34
Plano	yes	1.1	15"	Parshall Flume	30,000+	7,540	10
Richardson	yes	2.0	18" 15"	Parshall Flume	44,560	9,420	4
Mesquite	yes	---	--	Parshall Flume	9,163	9,420	26
Lewisville	yes	0.6	21"	Weir	6,434	5,500	25

it was felt that the Carrollton plant might not produce meaningful data and therefore, was not chosen because considerable sewage was bypassed during rainstorms and peak flow periods during the day, and because of the low efficiency in operation.

The Lewisville plant lies within the eastern city limits of the city and south of Garza-Little Elm Reservoir. This plant receives municipal sewage through a 21-inch vitrified clay pipe. The plant is composed of the following units: comminutor, wet well, and raw sewage pumping station equipped with one 1000 gallon-per-minute and one 500-gallon-per-minute pump, clarigester, trickling filter, and two oxidation lagoons. The 500-gallon-per-minute pump serves as a standby unit to handle peak inflow rates.

The 40-foot-diameter clarigester performs a dual-function. The top portion of the unit provides primary sedimentation with a 2-hour detention period and the lower portion provides anaerobic digestion of the solids removed in the upper unit. The digester has a six-inch sludge withdrawal line, at the bottom, that discharges onto sludge drying beds. Raw sewage is pumped into the center of the clarigester two feet below the water surface and empties radially into the periphery collection trough. The clarigester is equipped with a surface scum skimmer, a settled sludge rake, a digester scum breaker, and a digester sludge rake.

Secondary treatment units consists of a 100-foot diameter trickling filter with a 6-foot sidewall depth with the wastewater applied by a four-arm distributor. From the trickling filter, the effluent flows into the oxidation lagoons. A schematic of the plant layout and piping are shown in Figure 73.

Site Equipment and Instrumentation. Since the Lewisville treatment plant was a straight-line system, only one flow-measuring device was necessary to measure the flow through all of the units. The desired flow measurement was obtained by adapting the six-inch Foxboro Magnetic Flow Meter, used during the model sewer line testing, to the 10-inch cast iron clarigester influent line.

The polymer injector used for the 24-inch sewer line demonstration was also used for the treatment plant. Some modifications to the slurry feed system were necessary before the injector system would feed the proper rate of slurry because much larger slurry injection rates were used on the full-scale sewer line tests. Slurry injection rates were controlled by a small-capacity positive displacement pump driven by a variable speed electric motor instead of the vacuum provided by the eductor of the injection system. Figure 74 is a schematic diagram that shows the entire injection system used in treatment plant testing.

Since the raw sewage pump had a capacity greater than the raw sewage influent rate, the pump operated only 50 to 67 percent of the time. An operation time of 80 to 90 percent appears to be more desirable since nonsolvent flushing should be held to a minimum. The raw sewage pump discharge was fitted with a gate valve which allowed some flow adjustment to the treatment plant. As part of the testing procedure, the 1,000 gpm pump was throttled to obtain a flow of 700 gallons per minute and a longer operation time. The slurry injection rate was set proportionately to the raw sewage pump rate to achieve the proper polymer concentration in the sewage.

Polymer Slurries Used. Since the injection pump could only discharge as low as 0.07 gallon per minute with any degree of accuracy, the polymer content of the slurry was adjusted so that the injection rate would be in the more accurate pump range. For a polymer concentration of 50 milligrams per liter in the sewage, a slurry was used that contained 20 percent polymer powder. With this polymer content, the suspension capability decreased in the nonsolvent and therefore, the percentage of klucel H (gelling agent) was increased to one percent to offset the settling conditions. The solids content was altered for even lower polymer concentrations. Table XXIII describes the type of slurry used for three polymer concentrations and the slurry injection rates.

TABLE XXIII

TREATMENT PLANT SLURRY COMPONENTS

Polymer Concentration in Sewage (mg/l)	Slurry Components			Slurry Injection Rate (gpm)
	Polymer (%)	Gelling Agent (%)	Non Solvent (%)	
50	20	1	79	0.208
25	10	1.25	88.75	0.208
10	10	1.25	88.75	0.083

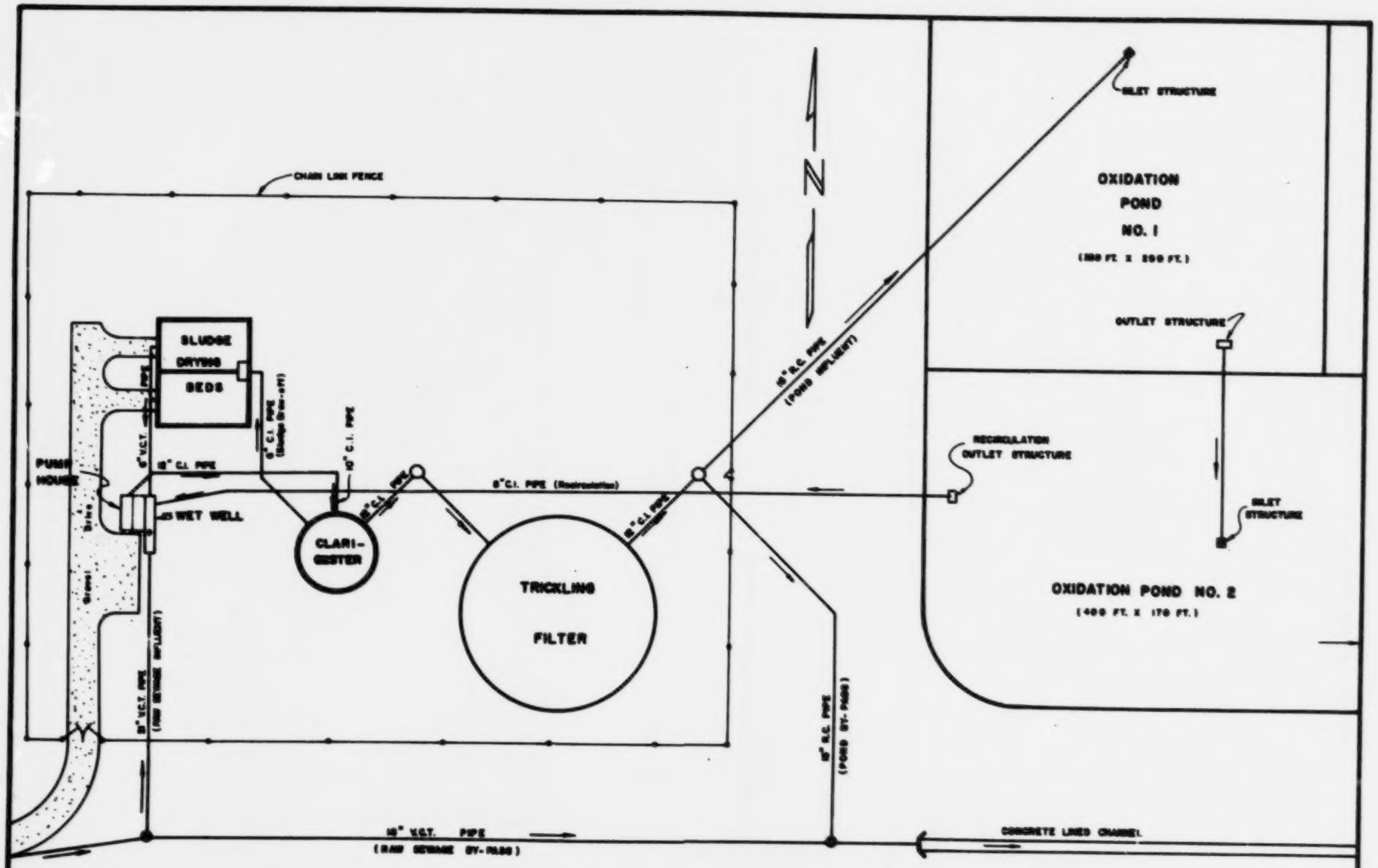

INLET STRUCTURE
OXIDATION
POND
NO. I
(180 FT. X 200 FT.)
OUTLET STRUCTURE
RECIRCULATION
OUTLET STRUCTURE
INLET
STRUCTURE
OXIDATION POND NO. 2
(400 FT. X 170 FT.)
N
CHAIN LINK FENCE
SLUDGE
DRYING
BEDS
PIPE
6" V.C.T.
6" C.I. PIPE
(Sludge Draw-off)
10" C.I. PIPE
12" C.I. PIPE
PUMP
HOUSE
Drive
Gravel
WET WELL
CLARI-
GESTER
10" C.I. PIPE
8" C.I. PIPE (Recirculation)
TRICKLING
FILTER
10" C.I. PIPE
10" R.C. PIPE
(POND INFLUENT)
10" R.C. PIPE
(POND BY-PASS)
18" V.C.T. PIPE
(RAW SEWAGE INFLUENT)
18" V.C.T. PIPE
(RAW SEWAGE BY-PASS)
CONCRETE LINED CHANNEL

FIGURE 73 LEWISVILLE WASTEWATER TREATMENT PLANT LAYOUT

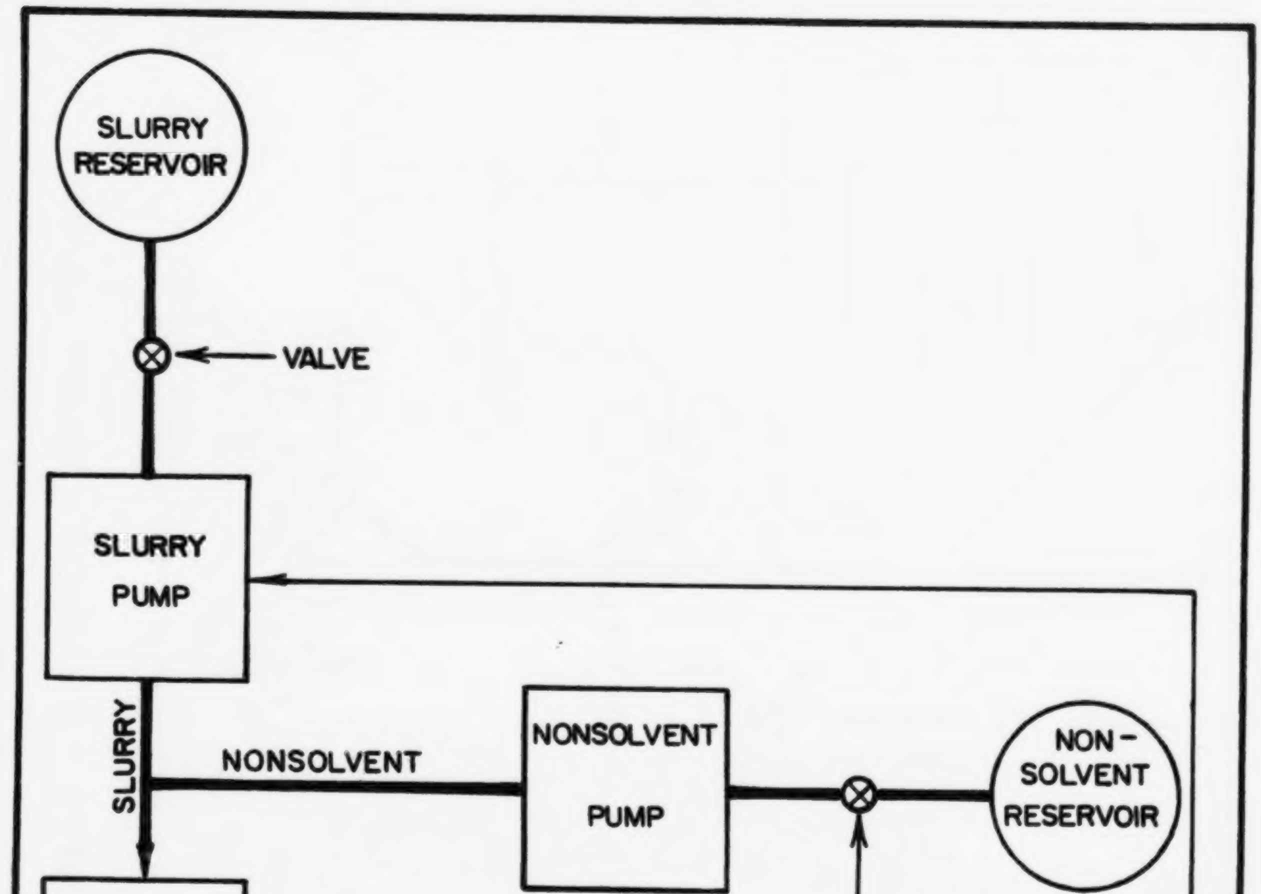

SLURRY RESERVOIR
VALVE
SLURRY PUMP
SLURRY
NONSOLVENT
NONSOLVENT PUMP
NON-SOLVENT RESERVOIR
VALVE
EDUCTOR
SEWAGE
SEWAGE + POLYMER
WET WELL
WET WELL PUMP ACTUATOR
RELAY SWITCH
ELECTRIC POWER (115 V)
ELECTRIC POWER (115 V)

FIGURE 74 - SCHEMATIC OF SLURRY INJECTOR SYSTEM USED FOR TREATMENT PLANT TESTS

Since cities using the polymer injection system may use one or several injectors, the test program to determine the effect of the polymers on treatment plants was designed to be conducted with a range of polymer concentrations, and the same two polymers (Polyox Coagulant-701 and WSR-301) that were injected into the 24-inch sewer line were injected into the wastewater at the Lewisville treatment plant.

Wastewater Treatment Plant Test Procedure. Each plant testing period of 24 hours was separated by at least 48 hours to allow the plant time to return, in general, to normal conditions. The test program was designed to have a matrix of nine tests (three tests for each polymer, one without polymer before the first polymer was injected, one without polymer between the two polymer operations, and one following the second polymer injection).

A reliable influent hydrograph for an average day was needed to determine 1) the quantity of slurry needed for a 24-hour operation, 2) the most desirable time to begin testing and polymer injection, and 3) when to take samples and what sample quantities were needed for preparing composite samples. Since available influent flow data was lacking influent hydrographs were developed by conducting 24-hour flow studies. Flow rates were computed by utilizing the magnetic flow meter installed, the number of on and off cycles of the 1000 gpm lift pump, wet well dimensions, and time required for the sewage level to rise a determined distance in the wet well.

During the plant tests program planning stage, one complete 24-hour flow study was made and a hydrograph plotted. The first flow study was conducted in December, 1968 (several weeks after any measurable rain) and was followed by several spot checks at later dates to insure a proper influent hydrograph. Two additional 24-hour flow studies were made following heavy rainfall periods that occurred during a break in the testing program. One study was made in February, 1969, six days after extremely heavy rainfall. The results of these two studies differed only slightly.

The positive displacement pump was connected to the variable speed drive, intake hoses, and discharge lines, and the pump's capacity at various revolutions per minute was calibrated. The time required to pump a known volume of 20 percent polymer slurry for each dial setting on the variable speed drive, produced a calibration curve of discharge rate (gpm) versus revolutions per minute (rpm). In addition, a curve of slurry injection rate versus discharge rate for various concentrations of polymer in sewage was plotted to aid in the proper injector dial selection.

The evaluation of polymer effects on sewage and wastewater treatment was conducted by measuring the parameters that would yield the most significant information on the performance of the primary clarifier, the trickling filter, and the oxidation ponds such as total solids, dissolved solids, suspended solids, settleable solids, BOD, COD, dissolved oxygen, and pH.

All analyses were made in accordance with the procedures outlined in the Twelfth Edition of Standard Methods for the Examination of Water and Wastewater.

Sewage sampling was done in such a manner as to provide the maximum data with a minimum of redundancy in testing. Five locations along the sewage treatment process were chosen to insure selective sampling:

> Wet Well (Station I). This point did not have any polymer, and provided raw sewage background data.
>
> Clarigester Inflow (Station II). Raw sewage and polymer mixed.
>
> Clarigester Outflow (Station III). Completion of primary treatment.
>
> Trickling Filter Outflow (Station IV). Completion of first stage of secondary treatment.
>
> Oxidation Pond Outflow (Station V). Completion of secondary treatment.

The tests for dissolved oxygen and pH were conducted at the sewage treatment plant during the test runs. For the remaining tests, composite samples were made and refrigerated until testing could be done in the laboratory. The time period for composite number one was from 7:30 a.m. to 5:00 p.m., since it was assumed that the raw sewage characteristics would remain fairly constant over that period. Composite number two was obtained from 5:00 p.m. to 2:00 a.m. the next morning. For the remaining time during the 24-hour run (2:00 a.m. to 7:30 a.m.), no samples were obtained since recirculation was employed during this period to maintain a satisfactory operating rate for the trickling filter distributor arm.

Both composites consisted of five sampling times spaced equally apart. The quantity of each sample was proportional to the flow rate at the time each sample was obtained, and was proportioned such that the total volume of each composite was one gallon as listed in Table XXIV.

Each test run was begun at approximately eight o'clock in the morning and terminated 24 hours later with polymer being injected for at least two hours before any samples were taken. The waiting time before sampling was based on a retention time study made with dye tracers which showed that within one hour after a Rhodamine dye was placed in the wet well, traces of the dye were picked up in the trickling filter effluent.

After the 1:30 a.m. sample was taken, the recirculation valve was opened at the secondary oxidation pond, and periodically increased to correspond with the decrease in raw sewage influent. As the influent rate

TABLE XXIV

TREATMENT PLANT TEST-RUN
SAMPLING TIMES AND AMOUNTS

Sample Number	Time	Sample Volume (ml)	Composite Sample Number
1	10:00 a.m.	845	1
2	12:00 noon	860	1
3	2:00 p.m.	830	1
4	4:00 p.m.	780	1
5	5:30 p.m.	715	2
6	7:30 p.m.	870	2
7	9:30 p.m.	880	2
8	11:30 p.m.	835	2
9	1:30 a.m.	485	2
10	8:00 a.m.	555	1

increased during the early daylight hours of the morning, the recirculation was decreased until raw sewage influent rate was sufficient to keep the plant operating, usually between 7:00 and 7:30 a.m. To complete the 24-hour test the last sample was taken at 8:00 a.m.

Before each 24-hour test period could begin, a number of changes had to be made in the plant's operation: 1) if recirculating had been employed during the night hours, the valve at the secondary oxidation pond had to be closed; 2) the wet-well pump was throttled down to 700 gallons per minute; 3) all sampling locations were cleaned, and the slurry injection system was connected and placed into operation when polymer tests were conducted.

To insure proper injection rates and functioning of the injection equipment, surface level readings were taken constantly at the slurry reservoir and compared with the time the pump was running. Therefore, injection concentrations of polymer never varied more than ± 2 percent of the desired concentration. Immediately after each polymer injection ceased, all injection equipment was flushed, cleaned, disassembled, stored, and the plant was returned to normal operating conditions. All composite samples were rushed to the laboratory for analysis.

Test Results and Analysis. The purpose of the wastewater treatment tests was to determine what effects the use of polymers in a sewer system would have upon the plant's operation and efficiency.

The testing program was interrupted by an unexpected breakdown in the clarigester stirring mechanism after one non-polymer run and one polymer injection test (50 mg/l) had been completed in January, 1969.

The City of Lewisville decided not to repair the malfunction, but to utilize the clarigester as an Imhoff tank since a similar breakdown during the summer of 1968 required several months to complete the repairs. Rather than wait for the City to repair the plant, or select a new treatment plant to complete the test program, the FWPCA suggested that meaningful results might be obtained by using the clarigester as an Imhoff tank. During the interim from plant breakdown to approval to proceed with testing operations (March, 1969) sludge was drained from the clarigester by the City. During this time, the sewage samples were analyzed and data obtained during the first two runs was evaluated.

Results of the one polymer injection test completed agreed with the results from the laboratory tests, i. e., injecting polymer slurry into a treatment plant system did not adversely affect treatment processes. On the other hand, this one test provided no conclusive evidence that settling rates or filtration rates were improved (percent removal of settleable and suspended solids and BOD are shown in Table XXV); however, a definite increase in suspended solids was noted. Performance of the clarifier was well below that expected for a primary treatment plant where 50 to 60 percent of the suspended solids and 30 to 35 percent of the BOD should be removed.

TABLE XXV

PERCENT REMOVAL OF APPLIED LOADING IN CLARIGESTER TEST SERIES 1

	Settleable Solids (%)	Suspended Solids (%)	BOD (%)	Polymer Concentration (%)
Non-Polymer	21	5	19	--
Polyox Coagulent-701	20	15	21	50

The data for the first two tests are tabulated in Tables XXVI and XXVII. The data indicates very little BOD removal in the trickling filter, with the majority being removed in the oxidation ponds.

The second series of tests were initiated during the middle of March, 1969, after the two flow studies were performed following heavy rains. The treatment plant had been in modified operation approximately one and a half months when the second series of tests began. The stirring mechanism was repaired during late February although many of the scum rods had been removed, producing a plant operation that was not the best. In addition, it was noted that very little slime or zoogleal growth or film was present on the rocks of the trickling filter. Below is a summary of the tests performed during the second series:

1) Non-polymer: March 13-14, 1969
2) 10 ppm of Polyox Coagulant-701: March 24-25, 1969.

TABLE XXVI

LEWISVILLE SEWAGE TREATMENT PLANT STUDIES
Non-Polymer Run
Dec. 26-27, 1968

Sample Identification	Temp. (°F)	Total Solids (mg/l)	Dissolved Solids (mg/l)	Suspended Solids (mg/l)	Settleable Solids (mg/l)	COD (mg/l)	BOD (mg/l)	D. O.	pH
I	62	1576	1371	205	228	423	175	1.75	7.4
II	61	1578	1371	207	228	426	188	1.75	7.4
III	62	1590	1379	191	180	315	152	2.5	7.4
IV	62	1479	1376	103	168	438	148	4.75	7.7
V	58	1468	1377	91	153	528	73	5.6	7.6

TABLE XXVII

LEWISVILLE SEWAGE TREATMENT PLANT STUDIES
Polymer Run (50 ppm Polyox Coagulant 701)
Jan. 6-7, 1969

Sample Identification	Temp. (°F)	Total Solids (mg/l)	Dissolved Solids (mg/l)	Suspended Solids (mg/l)	Settleable Solids (mg/l)	COD (mg/l)	BOD (mg/l)	D. O.	pH
I	61	1572	1450	142	224	488	98	2.3	7.4
II	61	1660	1482	178	232	828	168	1.5	7.55
III	59	1594	1458	136	185	630	132	1.65	7.4
IV	59	1522	1440	82	170	450	113	5.1	7.7
V	55	1510	1473	37	135	146	53	2.6	7.6

3) 25 ppm of Polyox Coagulant-701: March 27-28, 1969.
4) Non-polymer: March 31 and April 1, 1969.

Analysis of the data disclosed that plant efficiency had not improved any since prior to the breakdown when initial tests were conducted.

Sludge removed from the clarigester, normally every six to eight weeks, to the sludge drying beds had the color and odor characteristic of septic and undigested sludge. Moreover, during the testing, strong bubbling action occurred on the surface of the clarifier as a result of gases escaping from the digester through cracks existing in the floor of the clarifier. It was theorized that grease build up in the ceiling of the digester had plugged the gas collection chamber and gas could not escape. Also, over the years that the plant has been in existance, the depth of the primary oxidation pond has greatly reduced from the design depth of three feet, as islands of solids deposits are visible in a number of places. The percent removal of settleable solids, suspended solids, and BOD are shown in Table XXVIII.

A tabulation of the results of the second series of tests are given in Tables XXIX to XXXII. Results of the second series of tests indicate trends similar to those found in the first series, differing only in the raw sewage loading. If the most reliable settleable solids data is averaged for all the test operations, the percent removed in the clarifier is 23 percent (7 percent through the trickling filter, and 16 percent through the oxidation ponds). The BOD content of the final effluent was lowest for the last two polymer runs, except for one non-polymer test. The final COD content of the effluent, ranged between 140 mg/l and 170 mg/l, except for the one non-polymer test, with the initial clarifier loading in COD varying from 425 mg/l to 940 mg/l.

Although no definite improvements in filtration and sedimentation rates were detected while injecting the polymer into the sewage, it should be noted that no adverse effects developed under the conditions of polymer applications at the Lewisville plant.

TABLE XXVIII

PERCENT REMOVAL OF APPLIED LOADING IN CLARIGESTER TEST SERIES 2

	Settleable Solids (%)	Suspended Solids (%)	BOD (%)	Polymer Concentration (%)
Non-Polymer (1)	24	31	34	--
Non-Polymer (2)	33	24	26	--
Polyox Coagulant-701	30	37	36	10
Polyox Coagulant-701	32	24	2	25

TABLE XXIX

LEWISVILLE SEWAGE TREATMENT PLANT STUDIES
Non-Polymer Run: March 13-14, 1969

Sample Identification	Temp. (°F)	Total Solids (mg/l)	Dissolved Solids (mg/l)	Suspended Solids (mg/l)	Settleable Solids (mg/l)	COD (mg/l)	BOD (mg/l)	D. O. (mg/l)	pH
1-I	60	1613	1445	168	239	470	150	1.8	7.3
1-II	59	1578	1417	161	251	477	200	1.4	7.2
1-III	58	1490	1389	101	168	394	70	2.7	7.4
1-IV	57	1447	1368	79	152	239	10	5.8	7.6
1-V	56	1443	1370	73	146	146	30	6.2	7.7
2-I	60	1580	1389	191	224	532	208	2.2	6.9
2-II	59	1610	1413	197	212	749	180	2.1	7.3
2-III	60	1508	1420	88	185	488	180	3.2	7.3
2-IV	58	1459	1416	43	179	279	80	5.2	7.6
2-V	56	1376	1371	5	149	167	60	8.5	7.7
Avg. for Run I	60	1597	1417	180	232	501	179	2.0	7.1
II	59	1594	1415	179	232	663	190	1.8	7.25
III	59	1499	1405	94	177	441	125	3.0	7.35
IV	58	1453	1392	61	166	259	45	5.5	7.6
V	56	1410	1371	39	148	157	45	7.4	7.7

TABLE XXX

LEWISVILLE SEWAGE TREATMENT PLANT STUDIES
Polymer Run (10 ppm of Polyox Coagulant 701)
March 24-25, 1969

Sample Identification		Temp. (°F)	Total Solids (mg/l)	Dissolved Solids (mg/l)	Suspended Solids (mg/l)	Settleable Solids (mg/l)	COD (mg/l)	BOD (mg/l)	D.O. (mg/l)	pH
Composite 1	I	58	1528	1326	202	248	522	80	1.3	7.0
	II	58	1659	1360	299	302	818	155	1.9	7.4
	III	58	1392	1290	102	175	469	85	2.9	7.3
	IV	57	1262	1225	37	135	227	25	6.5	7.4
	V	54	1273	1211	62	132	162	10	5.4	7.4
Composite 2	I	60	1428	1358	70	225	424	92	2.1	7.3
	II	59	1419	1396	23	244	552	120	2.0	7.4
	III	57	1434	1410	24	204	421	90	2.8	7.4
	IV	58	1363	1359	4	192	235	55	6.3	7.7
	V	54	1259	1254	5	134	175	15	8.7	7.7
Avg. for Run	I	59	1478	1342	136	237	473	86	1.7	7.15
	II	58	1539	1378	161	273	685	138	1.9	7.4
	III	58	1413	1350	63	190	445	88	2.8	7.35
	IV	58	1313	1292	21	164	231	40	6.4	7.55
	V	54	1266	1233	33	133	169	13	7.0	7.55

TABLE XXXI

LEWISVILLE SEWAGE TREATMENT PLANT STUDIES
Polymer Run (25 ppm of Polyox Coagulant 701)
March 27-28, 1969

	Sample Identification	Temp. (°F)	Solids (mg/l)	Dissolved Solids (mg/l)	Suspended Solids (mg/l)	Settleable Solids (mg/l)	COD (mg/l)	BOD (mg/l)	D.O. (mg/l)	pH
Composite 1	I	62	1544	1337	207	240	547	70	2.1	7.5
	II	63	1574	1415	159	258	942	95	2.5	7.6
	III	62	1497	1391	106	179	686	65	3.0	7.4
	IV	61	1389	1342	47	175	446	25	5.7	7.7
	V	61	1344	1305	39	146	147	5	10.4	8.0
Composite 2	I	62	1538	1344	194	237	473	50	1.7	7.1
	II	61	1542	1383	159	249	947	80	2.0	7.3
	III	63	1510	1422	88	167	906	95	2.2	7.2
	IV	62	1442	1431	11	176	707	55	4.3	7.3
	V	63	1324	1317	7	137	135	20	12.1	8.1
Avg. for Run	I	62	1541	1341	200	239	510	60	1.9	7.3
	II	62	1558	1399	159	254	945	86	2.2	7.5
	III	62	1504	1407	97	173	796	80	2.6	7.3
	IV	62	1416	1387	29	176	572	40	5.0	7.5
	V	62	1334	1311	23	142	141	13	11.2	8.0

TABLE XXXII

LEWISVILLE SEWAGE TREATMENT PLANT STUDIES
Non-Polymer Run: March 31 - April 1, 1969

	Sample Identi-fication	Temp. (°F)	Solids (mg/l)	Dissolved Solids (mg/l)	Suspended Solids (mg/l)	Settleable Solids (mg/l)	COD (mg/l)	BOD (mg/l)	D. O. (mg/l)	pH
Composite 1	I	63	1467	1298	169	231	396	50	1.3	7.5
	II	62	1500	1262	238	265	404	55	1.2	7.6
	III	62	1374	1235	139	155	262	35	2.7	7.3
	IV	61	1375	1198	177	151	122	15	3.4	7.8
	V	58	1287	1176	111	133	170	5	5.8	8.2
Composite 2	I	63	1496	1262	234	237	425	48	0.4	7.1
	II	63	1519	1280	229	231	474	60	0.4	7.3
	III	62	1487	1310	177	177	369	50	0.5	7.2
	IV	63	1458	1313	145	156	189	18	1.0	7.5
	V	62	1268	1181	87	121	140	5	3.1	8.2
Avg. for Run	I	63	1482	1279	202	234	411	49	0.8	7.3
	II	62	1510	1271	239	248	439	58	0.8	7.45
	III	62	1413	1273	158	166	316	43	1.6	7.25
	IV	62	1412	1256	161	154	156	17	2.2	7.65
	V	60	1288	1179	99	127	155	5	4.5	8.2

SECTION VI

ECONOMIC ANALYSIS OF POLYMER USE

The Keen Branch Basin Sewer in Garland, Texas, was chosen for the economic analysis because of its history of frequent overflow, and because the City of Garland had plans for the development of a relief sewer which would yield specific cost data.

Figure 75 provides the general orientation of the study line which lies in the northwest section of the city where sewer construction requires rock excavation. The general slope of the Keen Branch is from west to east into the Duck Creek outfall sewer. Geologically, the black plastic clay soil overlays with a minimum cover of Austin chalk.

The area served by the existing sewer is not presently totally developed but, after total development occurs, the drainage basin will have approximately 1393 acres in residential and industrial development and about 304 acres in apartments and commercial establishments for a total of 1697 acres, or 2.65 square miles.

After complete development, design calculations indicate that at the system's upper end, two 10-inch sewers and one 6-inch sewer will contribute to the dual-line system a peak inflow of 4.1 million gallons per day. By the time the flow reaches Shiloh Road, the total flow in both sewer lines will be 9.6 mgd.

The old sewer line consists of 15-inch diameter clay sewer pipe, constructed at two different time periods. Initial construction was from the Duck Creek interceptor to Shiloh Road, and the secondary construction was from Shiloh Road to Yale Drive. In general, the old sewer invert or flow-line elevations rose from 521.40 feet at the Duck Creek sewer to 612.85 feet at Yale Drive or a total rise of 91.45 feet in a length of 13,010 feet for an average slope of 0.0039.

Existing lateral connections are such that the two lines are interconnected at several locations west of International Street, but east of this area the physiological development of the area and the topography precluded any interconnections of the two lines.

The new relief sewer will be constructed of 24-inch, 21-inch, 18-inch, and 15-inch diameter pipe and will empty into the Duck Creek outfall, downstream from the existing sewer line location.

The problem section in the existing 15-inch sewer is just west of Shiloh Road where the minimum slope changes from 0.0078 to 0.00326 for a distance of 1136.6 feet prior to an increased slope of 0.0060. The old sewer, when flowing just full on the 0.00326 slope, has a capacity of only 3.99 cubic feet per second (cfs), by using a selected Manning's "n" valve of 0.012 based upon the condition and alignment of the sewer.

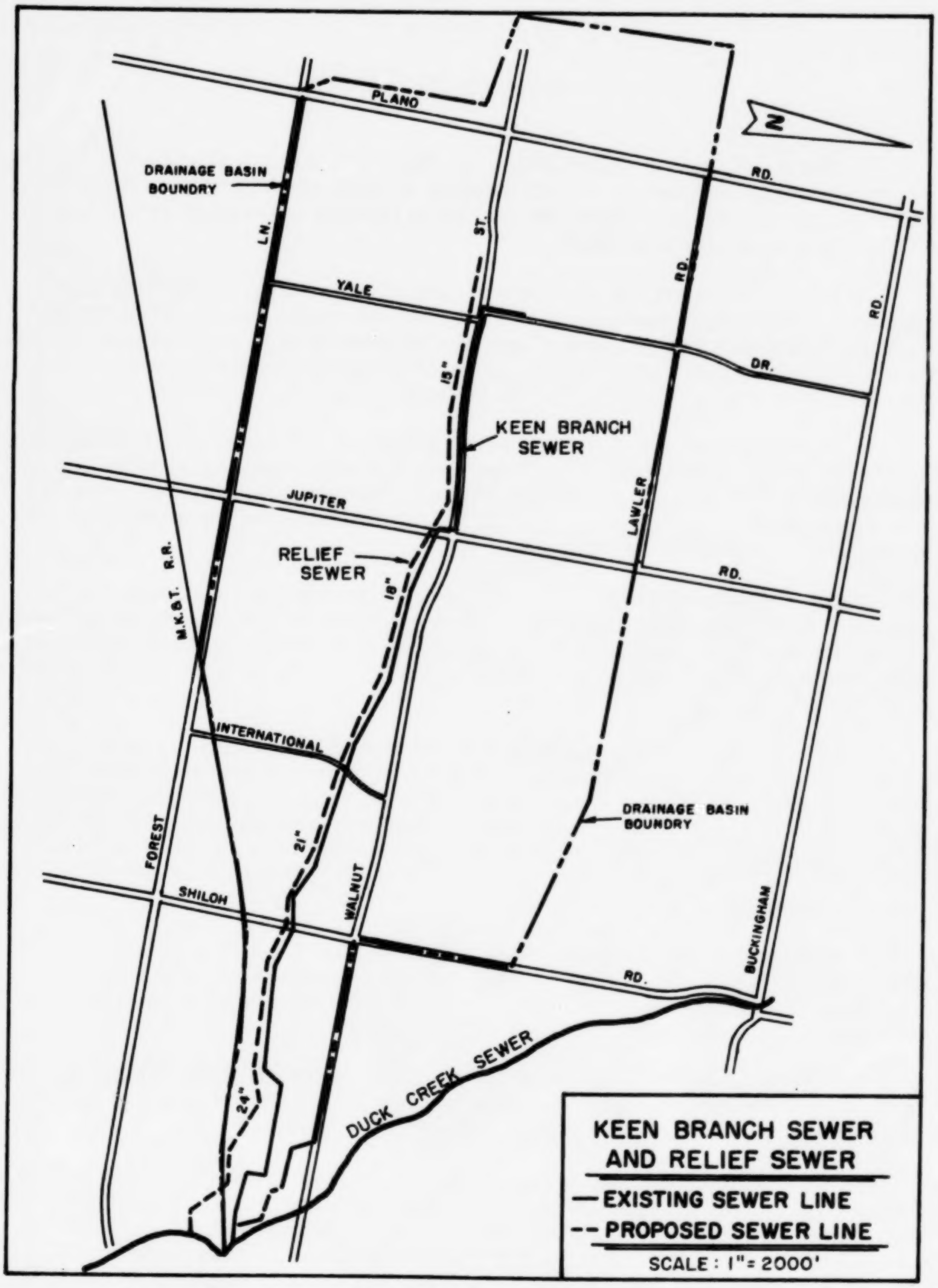

PLANO
RD.
N
DRAINAGE BASIN
BOUNDRY
LN.
ST.
RD.
RD.
YALE
DR.
15"
KEEN BRANCH
SEWER
JUPITER
LAWLER
RELIEF
SEWER
18"
RD.
M.K.& T. R.R.
INTERNATIONAL
21"
DRAINAGE BASIN
BOUNDRY
FOREST
WALNUT
SHILOH
BUCKINGHAM
RD.
DUCK CREEK SEWER
24"
KEEN BRANCH SEWER
AND RELIEF SEWER
EXISTING SEWER LINE
PROPOSED SEWER LINE
SCALE : 1" = 2000'

Figure 75. Sewer Line Location Used in Cost-Benefit Analysis in Garland, Texas.

If the 15-inch diameter pipe in this 1136.6 foot section is considered as just overflowing at both the upstream and downstream manholes, the pipe would have a capacity of 6.59 cfs as a result of the increased slope of the hydraulic gradient.

Before considering the specific costs of the relief sewer and the polymer injection on an average annual basis, it should be observed that no attempt was made to economically evaluate the indirect benefits of reducing sewage overflows onto streets and into creeks. The indirect economic benefits include the reduction of damage from sewage entering homes and businesses and the elimination of health hazards to individuals and the community.

Relief Sewer. The relief sewer was designed to consist of 2698 feet of 24-inch, 4315 feet of 21-inch, 3550 feet of 18-inch, and 2935 feet of 15-inch diameter clay tile pipe as shown in Table XXXIII. This table gives the tabulation of the winning bid for the construction of the sewer. Grades on the new line vary from 1.00 to 0.40 percent with most of the line located in the Keen Branch.

Recently, the City of Garland sold revenue bonds, to be amortized over a 30-year period at 5.7845 percent interest, to finance construction of several water utility projects, including sewers. This rate of interest and amortization period was applied to the Keen Branch Relief Sewer to provide the calculations shown in Table XXXIV.

The low bid of $394,861.15 was used in making the calculations for Table XXXIV, along with an engineering fee of $21,717.36 and an estimate of $6,000.00 for expenses that the City of Garland would incur for inspection and other items in conjunction with project construction. The resulting cost was $422,578.51, which was divided into 29 equal parts of $14,085.98 and one part of $14,086.09. The interest rate was applied to give the results shown in Table XXXIV.

A review of the City of Garland maintenance and operation costs for 1967-68 yielded that $131,689 was spent on the 279.9 miles of sewers. The costs averaged $470 per mile of sewer per year. Applied to the length of the Keen Branch, its average cost per year will be approximately $1202. Normally, such a project is under maintenance bond for the first year and maintenance costs are low in the initial service years and increase with age. So, by using $1202 as an average cost, the annual expenditure would vary from zero the first year to about $2400 in the thirtieth year. Therefore, if a $70 per year increase in maintenance cost is assumed, an operation and maintenance cost will result as tabulated in Table XXXIV.

By combining all costs involved in constructing the new sewer line, the average annual project cost over a 30 year period is $27,309.98.

Polymer Injection. Cost relative to the use of the polymer injection method of eliminating surcharges in sewers include equipment costs, material costs, and labor costs for both the production of the slurry and the

TABLE XXXIII

KEEN BRANCH CONTRACT BID TABULATION

Item	Description	Quantity	Unit Cost	Total Cost
1	6-inch VCT 0'-6'	40 LF	$ 4.75	$ 190.00
2	6-inch VCT 6'-8'	10 LF	4.75	47.50
3	6-inch VCT 8'-10'	15 LF	4.75	71.25
4	8-inch VCT 0'-6'	35 LF	5.10	178.50
5	8-inch VCT 6'-8'	35 LF	5.10	178.50
6	8-inch VCT 8'-10'	10 LF	5.10	51.00
7	8-inch VCT 10'-12'	40 LF	5.10	204.00
8	15-inch VCT 0'-6'	1,800 LF	16.75	30,150.00
9	15-inch VCT 6'-8'	20 LF	16.75	335.00
10	15-inch VCT 8'-10'	95 LF	19.85	1,885.75
11	15-inch VCT 10'-12'	320 LF	19.85	6,352.00
12	15-inch VCT 12'-14'	485 LF	19.85	9,627.25
13	15-inch VCT 14'-16'	215 LF	19.85	4,267.75
14	18-inch VCT 0'-6'	3,415 LF	19.30	65,909.50
15	18-inch VCT 6'-8'	5 LF	19.30	96.50
16	18-inch VCT 8'-10'	25 LF	19.30	482.50
17	18-inch VCT 10'-12'	105 LF	19.30	2,026.50
18	21-inch VCT 0'-6'	3,310 LF	20.85	69,013.50
19	21-inch VCT 6'-8'	1,035 LF	20.85	21,579.75
20	24-inch VCT 0'-6'	1,660 LF	23.80	39,508.00
21	24-inch VCT 6'-8'	965 LF	23.80	22,967.00
22	24-inch VCT 8'-10'	5 LF	23.80	119.00
23	24-inch VCT 10'-12'	10 LF	23.80	238.00
24	24-inch VCT 12'-14'	15 LF	23.80	357.00
25	24-inch VCT 14'-16'	10 LF	23.80	238.00
26	24-inch VCT 16'-18'	33 LF	23.80	785.40
27	Bore 16-inch CI inc. hole	85 LF	36.00	3,060.00
28	Bore 18-inch CI inc. hole	100 LF	40.00	4,000.00
29	Bore 24-inch CI inc. hole	85 LF	47.00	3,995.00
30	Bore under RR 24-inch CI	90 LF	93.50	8,415.00
31	24-inch CI Cl 150 0'-6'	30 LF	19.00	570.00
32	TY "S" MH Dallas 414-D-7	27 ea.	295.00	7,965.00
33	Std MH 4-foot Dia. 6 feet deep	8 ea.	289.00	2,312.00
34	Extra Depth MH	57 LF	20.00	1,140.00
35	For special MH at 91 + 00 and 101 + 59	30 CY	130.00	3,900.00
36	Cut and plug existing sewers	8 ea.	100.00	800.00
37	Connect existing MH	3 ea.	200.00	600.00
38	Lower 12 - inch CI water	10 LF	60.00	600.00
39	Cut and replace culvert floor	160 SY	10.00	1,600.00
40	Cut and replace asphalt paving	160 SY	13.00	2,080.00
41	Cut and replace concrete street paving	160 SY	8.00	1,280.00

TABLE XXXIII (Continued)

Item	Description	Quantity	Unit Cost	Total Cost
42	Cut and replace concrete sidewalk	140 SY	$ 1.00	$ 140.00
43	Pea gravel embd.	30 CY	7.00	210.00
44	Granular Mtl. embd.	50 CY	2.00	100.00
45	2,000 psi encasement	2,830 CY	13.50	38,205.00
46	Cone backfill excavation rock grout	3,220 CY	11.50	37,030.00
		TOTAL		$ 394,861.15

actual injection of the material. Costs were not included for vehicles that would be required since existing vehicles would be available in any water-utility organization.

Equipment. It was determined that a portable injection system would require one trailer for the injection equipment, including pump, hose, and special manhole cover, and one trailer for the slurry tank. The estimated cost of injection equipment, similar to that shown in Figure 66, is $6100, and the estimated cost of the slurry mixing tank, Figure 65, is $1600. Also, a modified pressure manhole cover, Figure 68, and water level recorder, Figure 61, facilitate the injection process. The estimated cost of these items are $300 and $200 each. Therefore, the total cost of the injection equipment is about $8200. By using the same cost analysis methods used in Table XXXIV, Table XXXV was tabulated. A 5.7845 percent interest rate and the estimated maintenance cost were used. Generally, the equipment will require some maintenance after each field use and time for this work has been included in the man hours of operation. Also, the equipment was assumed to have an economic life of 12 years after which the pump, hoses, and other parts will probably need replacement.

The total resulting cost per injection unit was determined to be $13,983.14 for an annual average cost of $1165.26 over a 12-year period.

Polymer Cost. Calculations on the 15-inch diameter sewer indicate that the capacity of the line just west of Shiloh Road (0.00326 slope) will carry 3.99 cubic feet per second when flowing just full. If the sewer was overflowing at the upstream and downstream manholes, the flow capacity would increase to 6.59 cfs; however, the systems should carry 9.6 million gallons per day at this location when the total contributory area is completely developed. Therefore, for the polymer injection, it was assumed that the 15-inch sewer would have to transport the full 9.6 mgd (14.8 cfs) which is 2.25 times the flow rate available when the upstream and downstream manholes are surcharged but not overflowing.

TABLE XXXIV

KEEN BRANCH RELIEF SEWER COSTS

Year	Annual First Cost ($)	Interest on Bonds ($)	Estimated Maintenance And Operation Cost ($)	Total Estimated Annual Expense ($)
1	14,085.98	24,444.05	0	38,530.03
2	14,085.98	23,626.75	70.00	37,782.73
3	14,085.98	22,814.45	140.00	37,040.43
4	14,085.98	21,999.64	210.00	36,295.62
5	14,085.98	21,184.84	280.00	35,550.82
6	14,085.98	20,370.04	350.00	34,806.02
7	14,085.98	19,555.23	420.00	34,061.21
8	14,085.98	18,740.43	490.00	33,316.41
9	14,085.98	17,925.63	560.00	32,571.61
10	14,085.98	17,110.82	630.00	31,826.80
11	14,085.98	16,296.02	700.00	31,082.00
12	14,085.98	15,481.22	770.00	30,337.20
13	14,085.98	14,666.41	840.00	29,592.39
14	14,085.98	13,851.61	910.00	28,847.59
15	14,085.98	13,068.05	980.00	28,134.03
16	14,085.98	12,222.00	1,050.00	27,357.98
17	14,085.98	11,407.20	1,120.00	26,613.18
18	14,085.98	10,592.39	1,190.00	25,868.37
19	14,085.98	9,777.59	1,260.00	25,123.57
20	14,085.98	8,962.79	1,330.00	24,378.77
21	14,085.98	8,147.98	1,400.00	23,633.96
22	14,085.98	7,333.18	1,470.00	22,889.16
23	14,085.98	6,518.38	1,610.00	22,214.36
24	14,085.98	5,703.57	1,680.00	21,469.55
25	14,085.98	4,888.77	1,750.00	20,724.75
26	14,085.98	4,073.97	1,820.00	19,979.95
27	14,085.98	3,259.16	1,890.00	19,235.14
28	14,085.98	2,444.36	1,960.00	18,490.34
29	14,085.98	1,629.56	2,030.00	17,745.54
30	14,085.98	814.75	2,100.00	17,000.73
Total	422,578.51	365,710.84	31,010.00	819,299.35

TABLE XXXV

PORTABLE INJECTION PLANT COSTS

Year	Annual First Cost ($)	Interest On First Cost ($)	Estimated Maintenance Cost ($)	Total Estimated Annual Expense ($)
1	683.33	474.33	100.00	1,257.66
2	683.33	434.80	125.00	1,243.13
3	683.33	395.27	150.00	1,280.60
4	683.33	355.75	175.00	1,214.08
5	683.33	316.22	200.00	1,199.55
6	683.33	276.69	225.00	1,185.02
7	683.33	237.16	250.00	1.185.02
8	683.33	197.64	275.00	1,170.49
9	683.33	158.11	300.00	1,155.97
10	683.33	118.58	300.00	1,141.44
11	683.33	79.06	300.00	1,101.91
12	683.33	39.53	300.00	1,062.39
Total	8,200.00	3,083.14	2,700.00	13,983.14

During the spring of 1967, observations were made of the 15-inch line, and it was determined that the line would overflow at one or more points when the rainfall exceeded 2.25 inches one day and 1.19 inches the following day. The observation manholes overflowed on the second day for a four-hour period.

Table XXXVI shows the critical rainfall when sewer overflows would likely have occurred for the years 1963 to 1966 (three full years). The rainfall data was taken at Dallas Love Field, which is approximately 15 miles from the Garland bottleneck site. Local thunder showers may occur at Love Field which do not occur at Garland; however, double mass curve studies have shown that the long-range rainfall does not differ appreciably.

An estimate of the time of overflow on the line was made for each of the storm periods, based upon the amount of rainfall and the antecedent time, which are shown in Table XXXVI.

TABLE XXXVI

ESTIMATES OF POLYMER USE

Year	Month	Day	Number Of Storms	Rainfall (Inches)	Estimated Time of Overflow (Hours)	Volume of Flow (MG)	WSR-301 Polymer Dosage (Mg/l)	Pounds of Polymer
1963	April	21	1	0.92				
		27	2	1.17				
		28		2.39	8	3.200	50	1,334.4
1964	March	8	3	1.73	3	1.200	50	500.4
	May	29	4	1.44				
		30		0.59	1	0.400	50	166.8
	Aug.	15	5	2.48				
		16		0.55	6	2.400	50	1.000.8
	Sept.	20	6	2.17	3	1.200	50	500.4
		21		3.25	8	3.200	50	1,334.4
		22		2.15	12	4.800	50	2,001.6
	Nov.	3	7	1.76				
		4		0.96	5	2.000	50	834.0
1965	Feb.	8	8	1.55				
		9		1.82	8	3.200	50	1,334.4
	May	10	9	4.54	10	4.000	50	1,668.0
	Sept.	21	10	4.32	10	4.000	50	1,668.0
1966	Feb.	9	11	2.32	6	2.400	50	1,000.8
	April	23	12	1.86				
		24		1.25	2	0.800	50	333.6
		25		2.33	6	2.400	50	1,000.8
		28	13	3.60	8	3.200	50	1,334.4
		29		1.84	4	1.600	50	667.2
		30		1.02	2	0.800	50	333.6
Average Per Year			4.33		6	2.400	50	1,000.8

The worst flow conditions would occur when the flow of 9.6 mgd lasted for the entire overflow time period. By assuming this flow condition, and the use of WSR-301 polymer slurry injected at a rate sufficient to provide 50 mg/l polymer concentration, the quantity of polymer for all storm overflows totaled 17,014 pounds. This volume of polymer was converted into an annual average quantity by using the approximate average of 4.25 storms per year (Table XXXVI). The annual average polymer use was calculated to be 4253 pounds. By using a unit cost of $0.80 per pound, the total cost for polymer would be $3402.72 annually.

Since the slurry is only 30 percent by weight polymer, the costs of the nonsolvent and gelling agent must be included. The cost of isopropyl alcohol is $0.69 per gallon or $0.113 per pound. The gelling agent cost $1.30 per pound. By combining all material cost and based on a use of 4253 pounds of WSR-301, the annual cost of slurry is $4608.35.

Labor Costs. An intense review of the practice used in the field tests indicate that about 30 manhours were required to produce a batch of polymer slurry. This time also included cleanup and any maintenance during slurry production. At an hourly rate of $2.87, the slurry production cost would be approximately $366.

A review of the injection times in Table XXXVI shows that the average storm duration is 6.0 hours. When the 4.25 average number of storms per year is used, the result is 25.5 manhours per year for injection. By again using the $2.87 hourly rate, the annual labor costs for two men is $146.37. Combining all labor costs, a total of $658.66 annually is obtained.

When the annual average mobile injection plant and equipment cost of $1165.26 is combined with the annual estimated material cost of $4608.35 and the estimated labor cost of $658.66, the annual average cost of injecting WSR-301 to control flow in the existing 15-inch diameter Keen Branch Sewer is $6432.27. Although certain fixed expenses such as vehicle operation and general administrational costs were not included, the polymer cost was only one-fourth the annual average cost of building the relief sewer. It should be emphasized that one injection system was used in the above calculations. However, probably two injection units would be necessary on occasions. Therefore, the equipment cost would be twice that indicated with a slight increase in slurry material cost. If a city anticipated using this technique for flow control, additional units could be purchased based on the actual operating performance of an initial single unit.

Finally, it must be pointed out that the indirect benefits of both systems were not evaluated because of the difficulty involved in such an analysis.

In summary, the cost analysis based on construction of a relief sewer line resulted in an average cost of $27,310 per year. The cost analysis based upon the use of portable injection equipment and a polymer slurry during peak flow periods was $6432 per year.

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APPENDICES

Appendix A - Fluid Friction Reducing Polymers Literature Survey
Appendix B - Discussion of Fluid Modification by Polymers
Appendix C - Derivation of Graphs of Percent Flow Increase vs Polymer Concentration
Appendix D - Polymer Slurry Mixing Techniques

APPENDIX A

FLUID FRICTION REDUCING POLYMERS

LITERATURE SURVEY

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APPENDIX B

DISCUSSION OF FLUID MODIFICATION BY POLYMERS

The chemical and physical changes that polymers impart to fluids to provide viscous friction reduction cannot be fully explained. Currently, the change in flow phenomena that occurs when polymers, such as those selected for investigation in this program, are added to fluids is under intensive research by a number of investigators as indicated in Reference 1. Basically, previous studies have determined that polymers probably tend to act as "turbulence dampers" and, in effect, damp out the very irregular paths of the fluid particles near the wall and extend the laminar boundary layer further into the turbulent flow core. This damping effect causes the laminar sublayer to increase in thickness, resulting in a reduction in the wall velocity gradient and shear stress gradient which provides a reduction in the frictional resistance to flow, since the action of wall shear stress is to slow down the fluid near the wall.

Although this explanation makes the process of friction reduction by polymers appear less complicated, it has so far defied complete explanation. Some of the more obvious peculiarities of friction reduction resulting from using polymers are briefly discussed below.

The Critical Shear Stress. The shear stress at which a transition from ordinary turbulent flow to friction-reduced turbulent flow occurs, appears to have to be surpassed before the friction-reducing phenomena will take place; therefore, the Reynolds number must be in the turbulent region.

The So Called "Diameter Effect." A polymer of the same concentration will exhibit different levels of friction reduction in different sizes of pipe.

The "Shear Degradation of Polymer Effect." Some of the most effective friction-reducing polymers are found to be adversely affected by high shear environments such as imparted by some types of pumps.

Basic Characteristics of Polymer Friction Reduction

How polymers affect a fluid can be better understood by studying an actual flow curve such as that shown in Figure B1a and b. These graphs, taken from Reference 2, show actual pressure drops or frictional losses for water with various concentrations of Polyox Coagulant-701 in a 0.416-inch diameter pipe. The higher polymer concentrations tend to increase the viscosity (the fluid property that causes shear stress in a moving fluid since, without viscosity, there is no fluid resistance). As a result, a moderate increase in pressure drop in the laminar flow regime occurs as is shown in Figure B1a. It should be observed that the 2 and 10 mg/l polymer concentrations do not cause friction reduction immediately after transition from laminar to turbulent flow. This polymer solution characteristic occurs

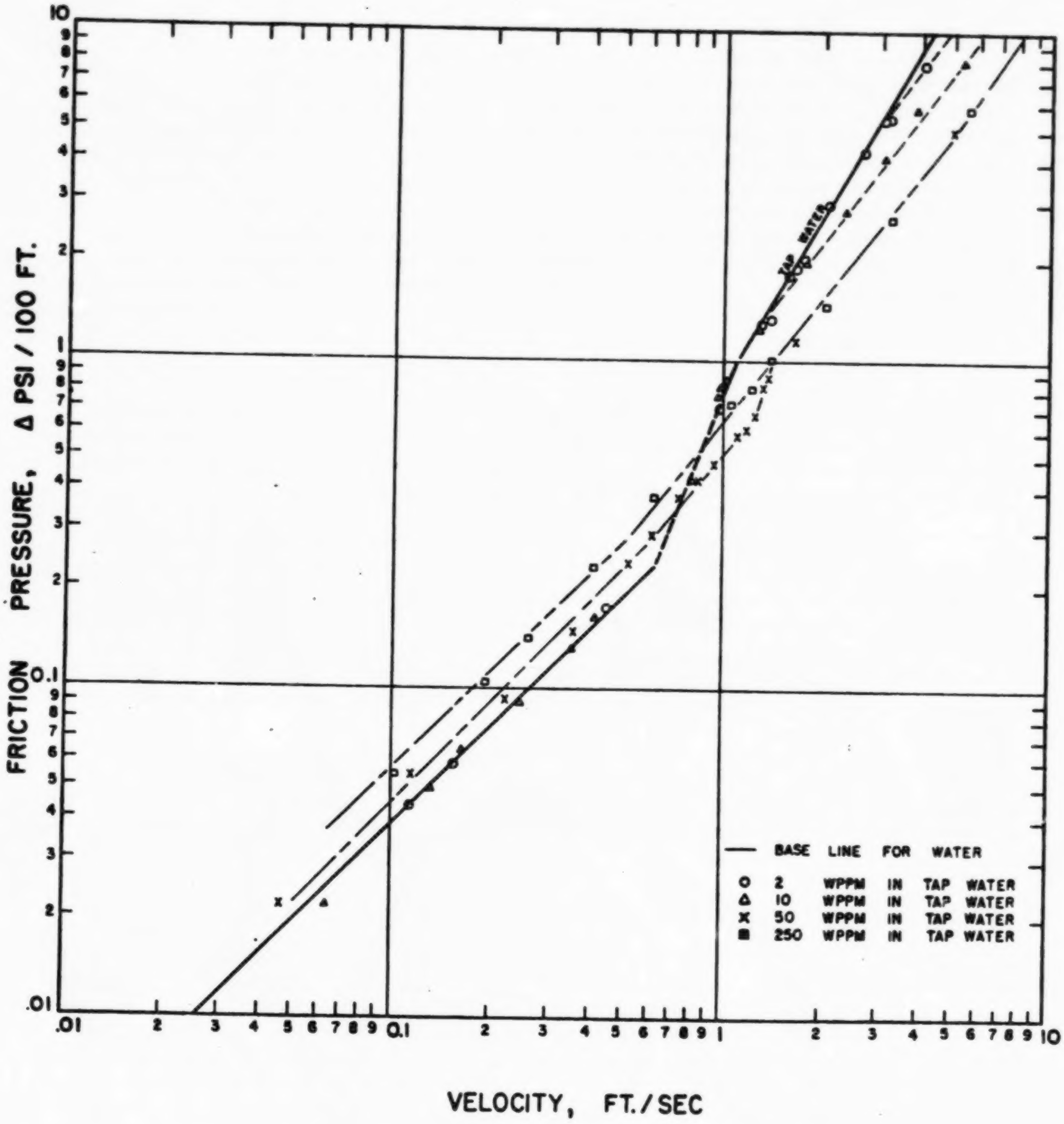

Figure B1a. Flow Studies in 0.416 Inch I.D. Tubing Tap Water With Indicated Concentrations of Polyox WSR-701.

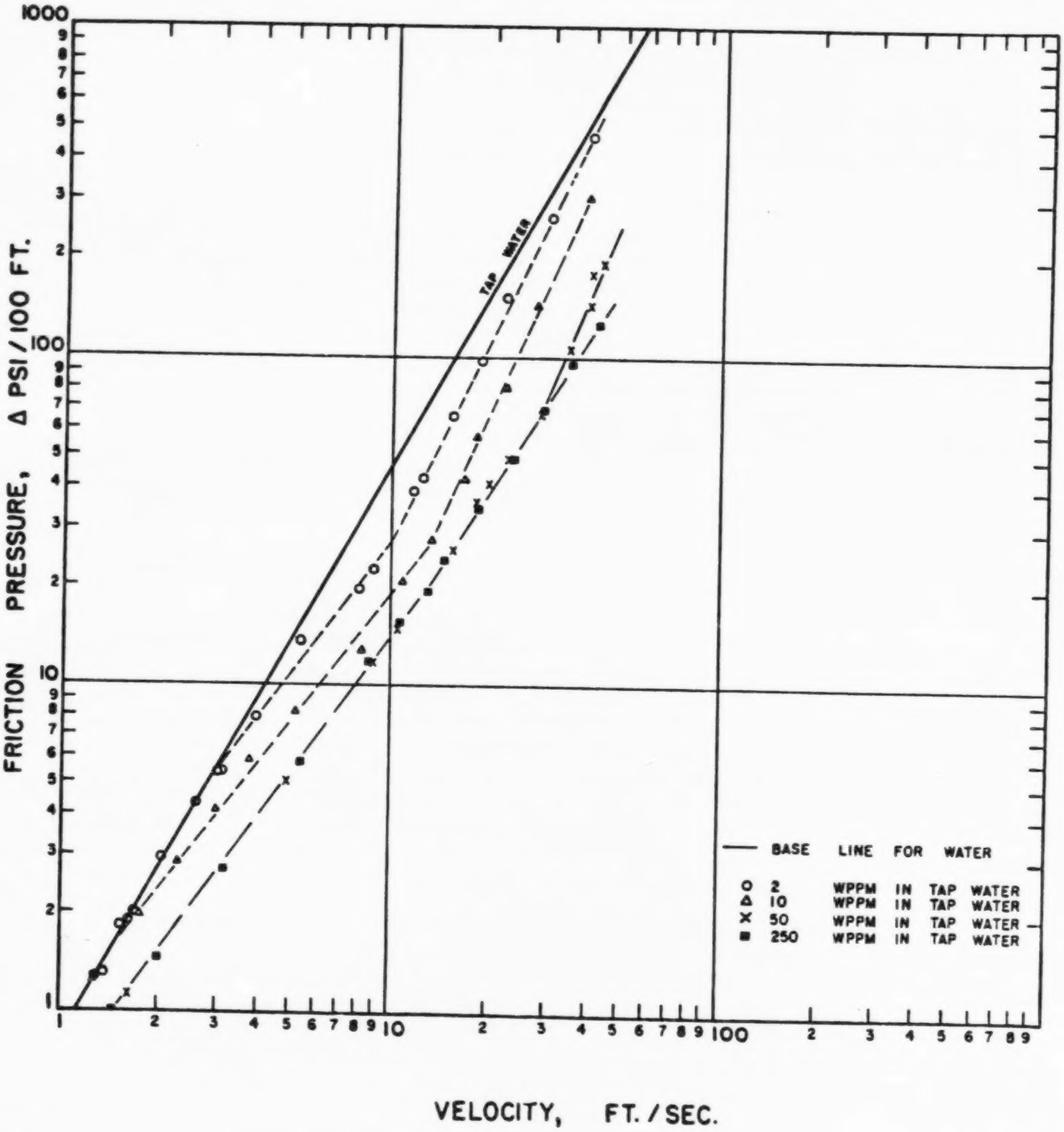

Figure B1b. Flow Studies in 0.416 Inch I.D. Tubing Tap Water With Indicated Concentrations of Polyox WSR-701.

because these solutions reach their critical shear stresses well after the flow has transitioned into the turbulent region.

In Figure B1b, it is seen that all polymer concentrations are exhibiting some friction reduction, although the 50 and 250 mg/l concentrations generally provide identical friction reduction (the 50 mg/l) concentration is near the optimum concentration for friction reduction in this size pipe and at these velocities; the 250 mg/l solution is unnecessarily high for maximum obtainable friction reduction in this flow system).

The shear degradation phenomenon is also illustrated in Figure B1b, by the 10 mg/l solution at flow velocities above 15 feet per second. This degradation was caused by the shear in the flow system pump, not by the shear stress in the pipe. On the other hand, the solution with 50 mg/l polymer concentration is unaffected at velocities up to 38 feet per second. Thus, it is apparent that the concentration of sensitive polymers (such as Polyox Coagulant-701 and WSR-301) must be increased above that normally required for optimum friction reduction if passage through a pump prior to entering a conveyance system will occur. In this way, enough of the polymer will survive the high shear environment to give the desired friction reduction. Unfortunately, the additional amount of polymer required to survive this high shear environment cannot presently be predicted and must be determined experimentally.

Flow Control by Using Polymers

The ways in which some polymers can be used to improve and control the flow performance of fluids in conduits are illustrated in Figure B2. In this figure, laminar and turbulent flow curves are illustrated for water and for water with an optimum concentration of polymer. In the laminar region, the water with additive will generally exhibit a slight increase in frictional losses because of the additive's viscosity effect on the fluid. In the turbulent region, the optimum polymer concentration will cause frictional losses to be reduced by 80 to 85 percent (Reference B). This percent friction reduction is limited by the extrapolated laminar flow line, since the minimum friction loss possible is that exhibited by laminar flow.

The types of flow performance changes which can be effected by using polymers to modify fluids are illustrated by the lines A-B, A-C, and A-D in Figure B2. One common way of expressing the flow performance obtained is percent friction reduction. Percent friction reduction, illustrated by line A-B, is defined at a constant flow rate by the ratio of frictional loss or pressure difference at points A, B, and B'. By using such data points, the percent friction reduction can be calculated by the equation

$$\frac{A-B}{A-B'} \times 100.$$

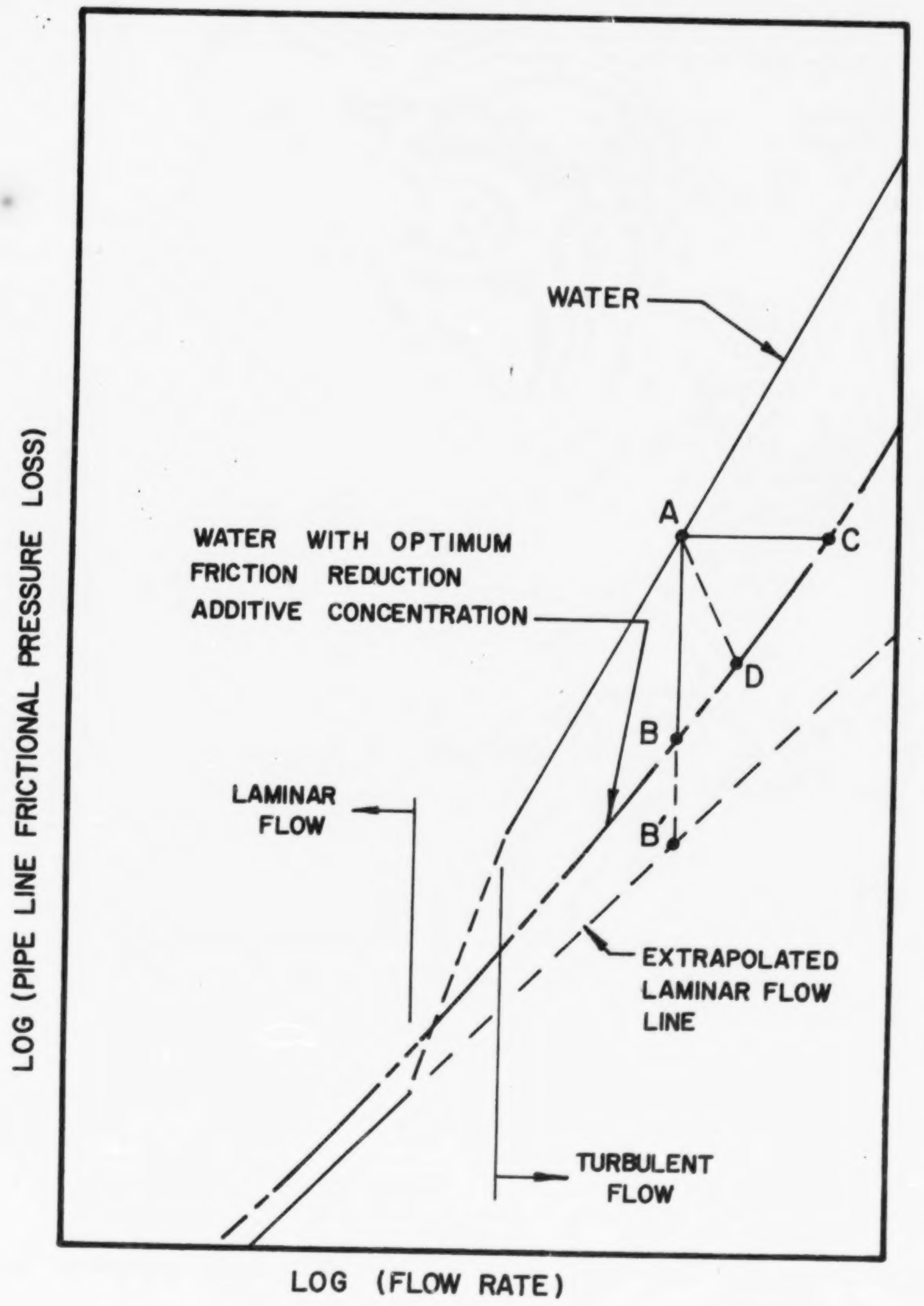

Figure B2. Examples of Flow Modification of Water by Polymers.

The constant flow rate friction reduction indicates that the frictional losses within a fluid (in turbulent flow) can be reduced up to 85 percent by using optimum polymer concentration.

Another common method of expressing flow performance is by percent flow increase, as illustrated by line A-C. These points illustrate that the flow rate can be increased (by maintaining a constant energy level to obviate the friction losses or pressure drop along a pipe system) up to 140 percent by using an optimum concentration of polymer in the fluid (Reference 1). This flow increase is defined as percent flow increase, or

$$\frac{C - A}{A} \times 100.$$

A better understanding of how polymers can affect a gravity flow system can be obtained by considering the following flow system. Assume a gravity flow system with two long, large-diameter sections joined by a section of moderate length but of smaller diameter. During peak flow conditions, the small diameter pipe's capacity is inadequate to carry the flow, causing a surcharge or static head to build up in the upstream section (Figure B3a). The total friction loss head, H_1, is equal to the sum of the friction losses in each section of the line, H_2 and H_3. The head losses due to frictional resistance to flow in the small-diameter section is assumed to be sufficient to overflow the upstream section.

By injecting an adequate concentration of polymer upstream from the restricted section, the maximum obtainable frictional loss reduction could be obtained if the flow remained constant; however, the friction reduction obtained in the downstream restricted section and large diameter section will cause the total frictional head to be reduced to h_1 (see Figure B3b). This reduction in frictional resistance to flow will cause the flow rate to stabilize at a somewhat higher rate; i.e., the flow adjusts itself from point A to point D as in Figure B2. This point indicates that both a head drop and a flow increase occurred to obtain a new equilibrium flow condition.

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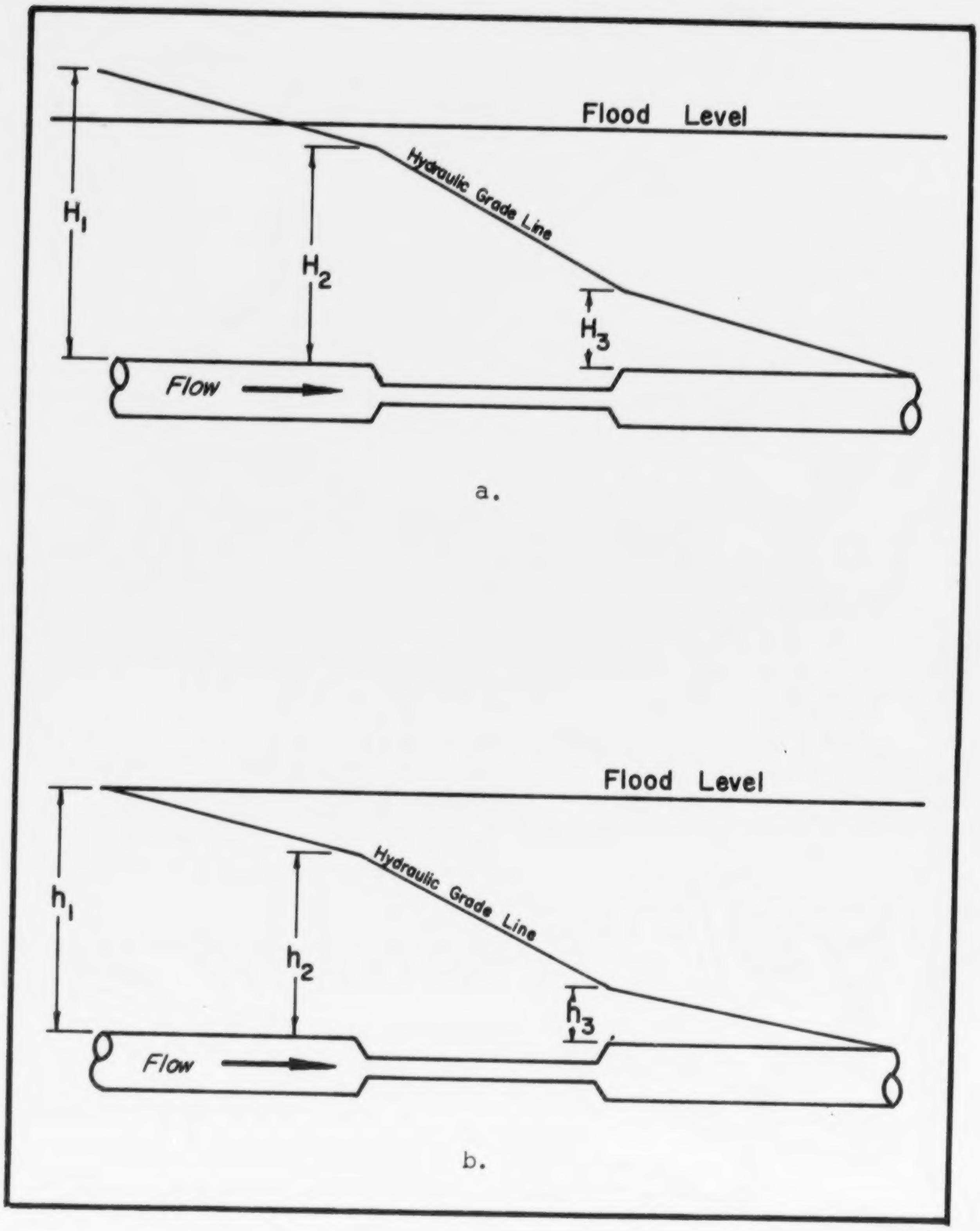
Flood Level
Hydraulic Grade Line
H_1
H_2
H_3
Flow
a.
Flood Level
Hydraulic Grade Line
h_1
h_2
h_3
Flow
b.

Figure B3. Friction Head Reduction Effects Obtained by Using Polymers.

APPENDIX C

DERIVATION OF GRAPHS OF PERCENT FLOW INCREASE VS POLYMER CONCENTRATION

A discussion of how polymers can modify such fluids as water and wastewater is presented in Appendix B, where it is shown that flow performance can be expressed as 1) percent friction reduction, at a constant flow rate, or 2) percent flow increase at a constant energy or static head level, or 3) a combination of both flow increase and friction reduction, as in the case of gravity flow systems. Also, this discussion explained that polymers affect fluids by decreasing turbulant flow losses. Therefore, by maintaining a constant flow rate, a reduction in the head required to overcome frictional losses will occur; however, if a constant energy level is maintained, the flow can be increased until frictional losses again equal the energy level available to drive the fluid.

In the six-inch flow tests conducted during this program, almost constant water and sewage flow rates were maintained both before and during polymer injection; however, during the period polymer was injected, a slight increase in flow rate occurred due to the addition of the highly concentrated polymer solutions. To obtain a polymer concentration of 200 mg/l in a sewage flow rate of 550 gpm, the necessary injection rate for Polyox Coagulant-701 and WSR-301 slurries was 23 gpm, resulting in a total flow rate of 573 gpm.

Similar slight flow increases were imposed on the 350 and 450 gpm flow rates for 50 mg/l and 100 mg/l, as shown in Figures C1 through C6. These figures show the measured pressure or friction drop obtained for the three flow rates in the 30-foot test length of six-inch diameter pipe.

During each test, the pressure drop for turbulent flow was measured at each of the three flow rates. A polymer solution was then added and the pressure drop again determined after steady flow was again obtained at each flow rate. These data points are shown for water and sewage at 73°F in the above figures. Similar graphs were prepared from data points for each polymer tested.

To determine each polymer's effectiveness as a reducer of frictional losses, the percent flow increase was determined from graphs (similar to those shown in Figures C1 through C6) of various polymer concentrations (Table XVII presents the test data matrix).

Figure C7 illustrates how the percent flow increase was derived from the graphs of flow rate versus pressure drop. To avoid extrapolating beyond the limits of the data obtained, 250 and 300 gpm were selected for calculating the flow increase.

The flow versus pressure drop graphs were entered at 300 gpm, and the maximum pressure drop was determined for this flow rate (the value at

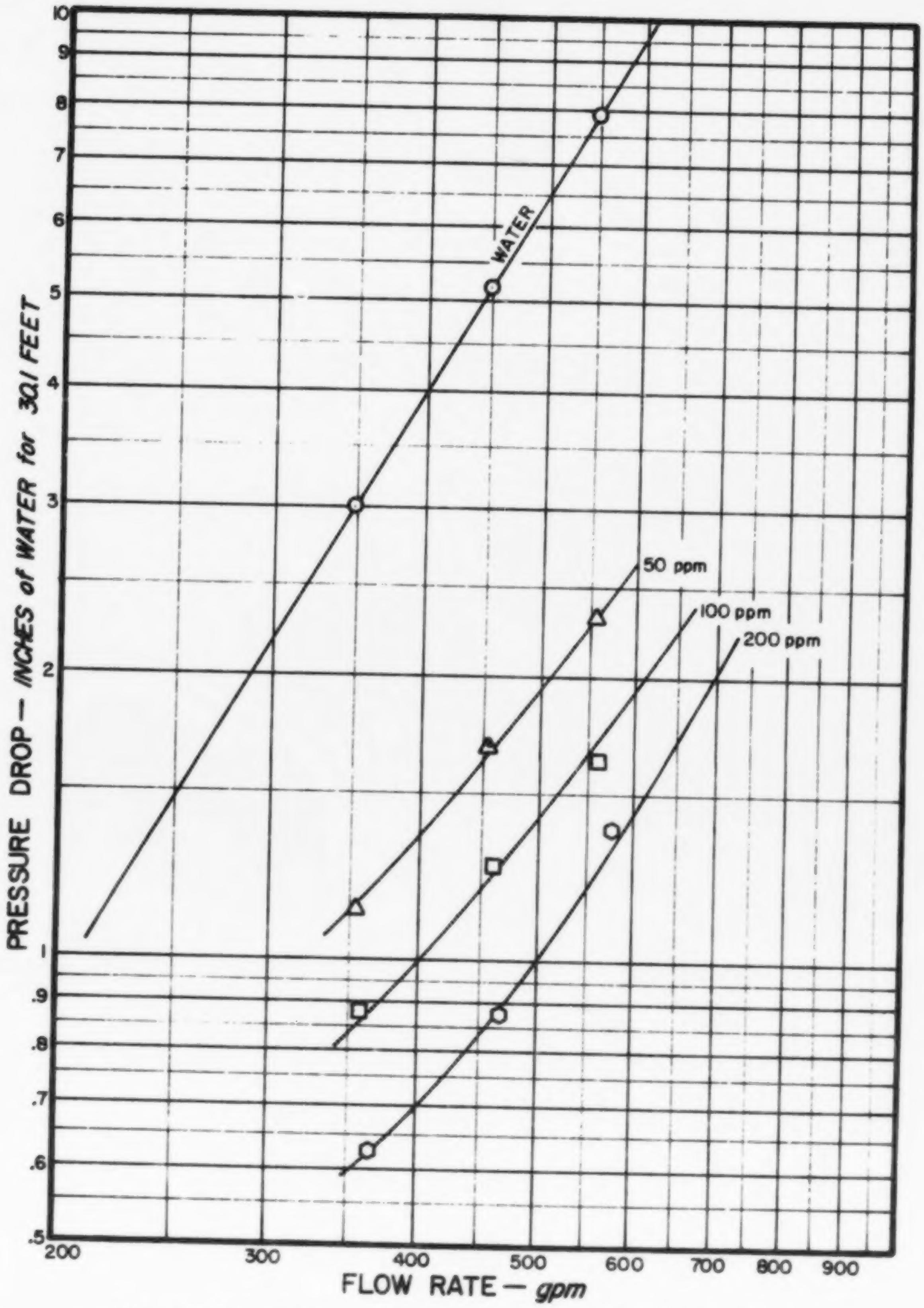

Figure C1. Polyox Coagulant-701 in Six-Inch Test Facility at 73^{0}F in Water.

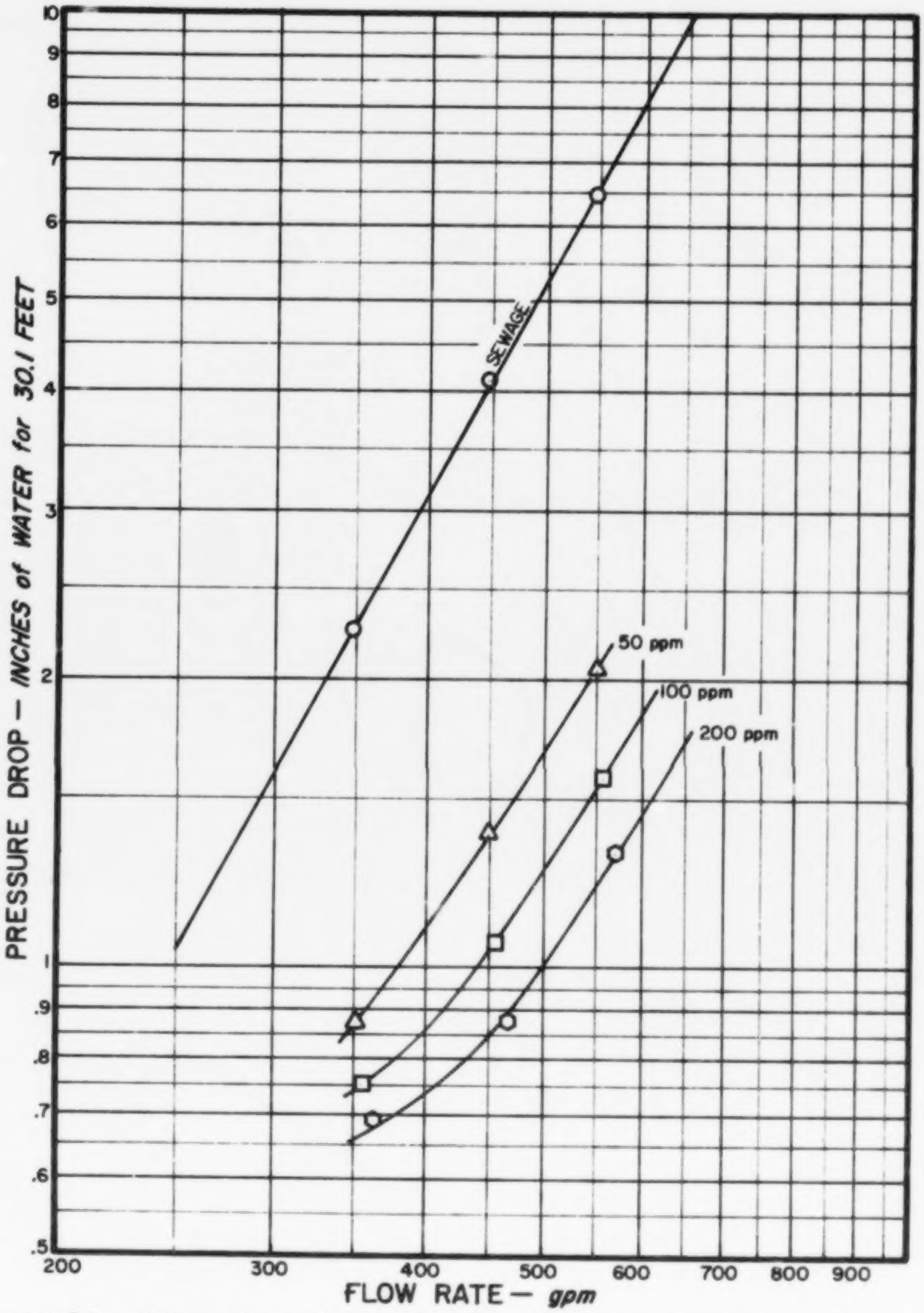

Figure C2. Polyox Coagulant-701 in Six-Inch Test Facility at 73°F in Sewage (3 ml/l Settleable Solids).

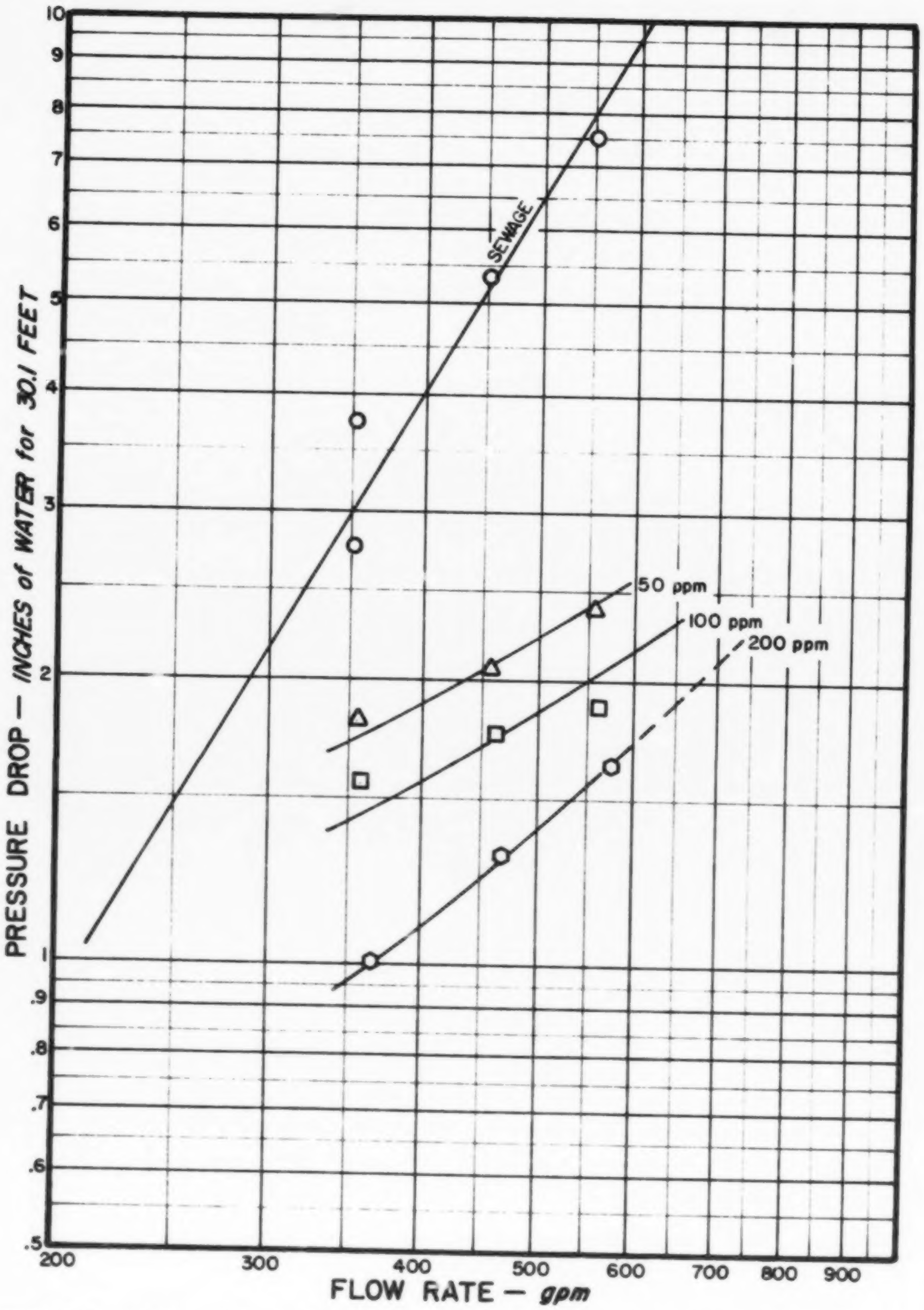

Figure C3. Polyox Coagulant-701 in Six-Inch Test Facility at 73°F in Sewage (9 ml/l Settleable Solids).

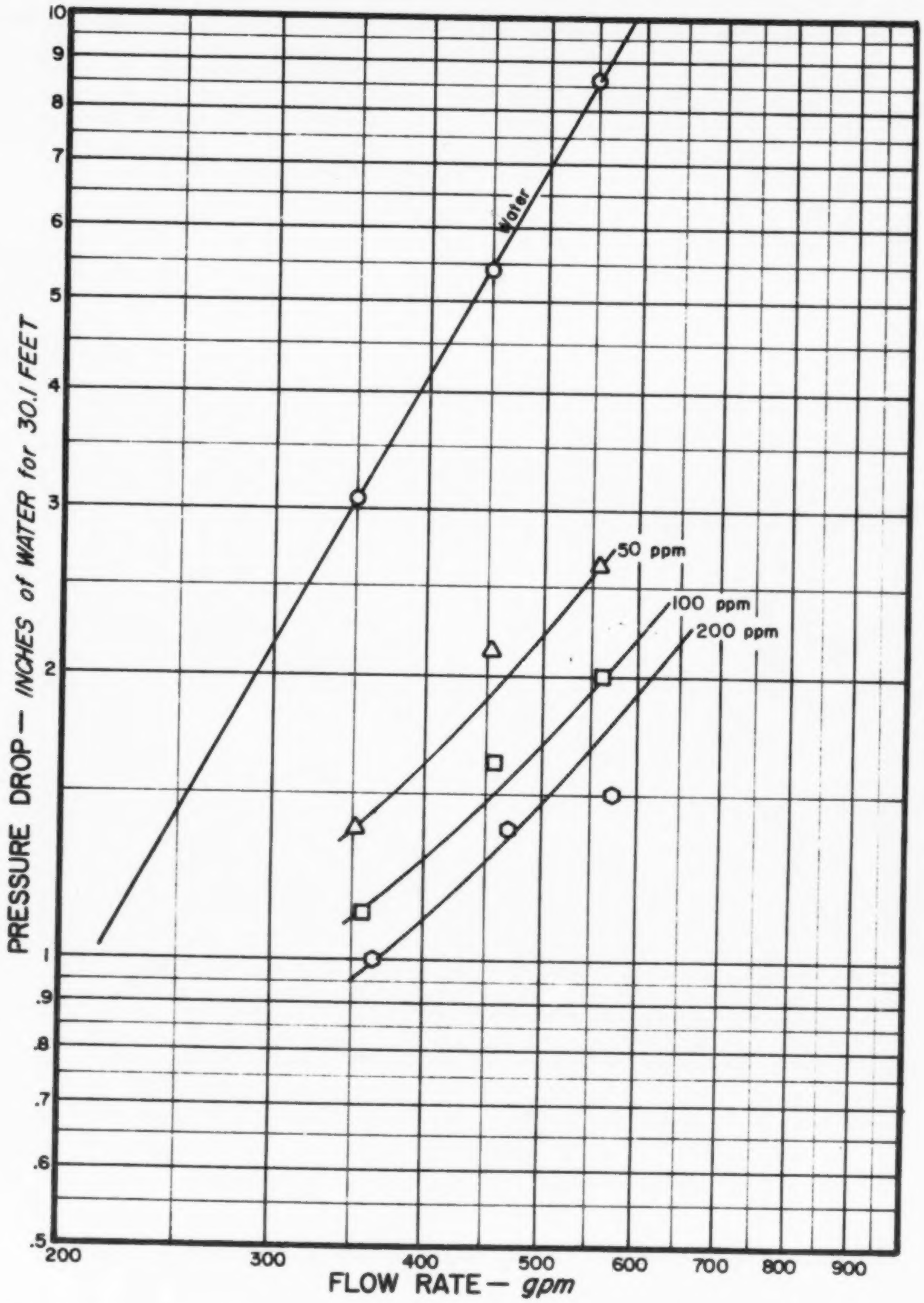

Figure C4. WSR-301 in Six-Inch Test Facility at 70°F in Water.

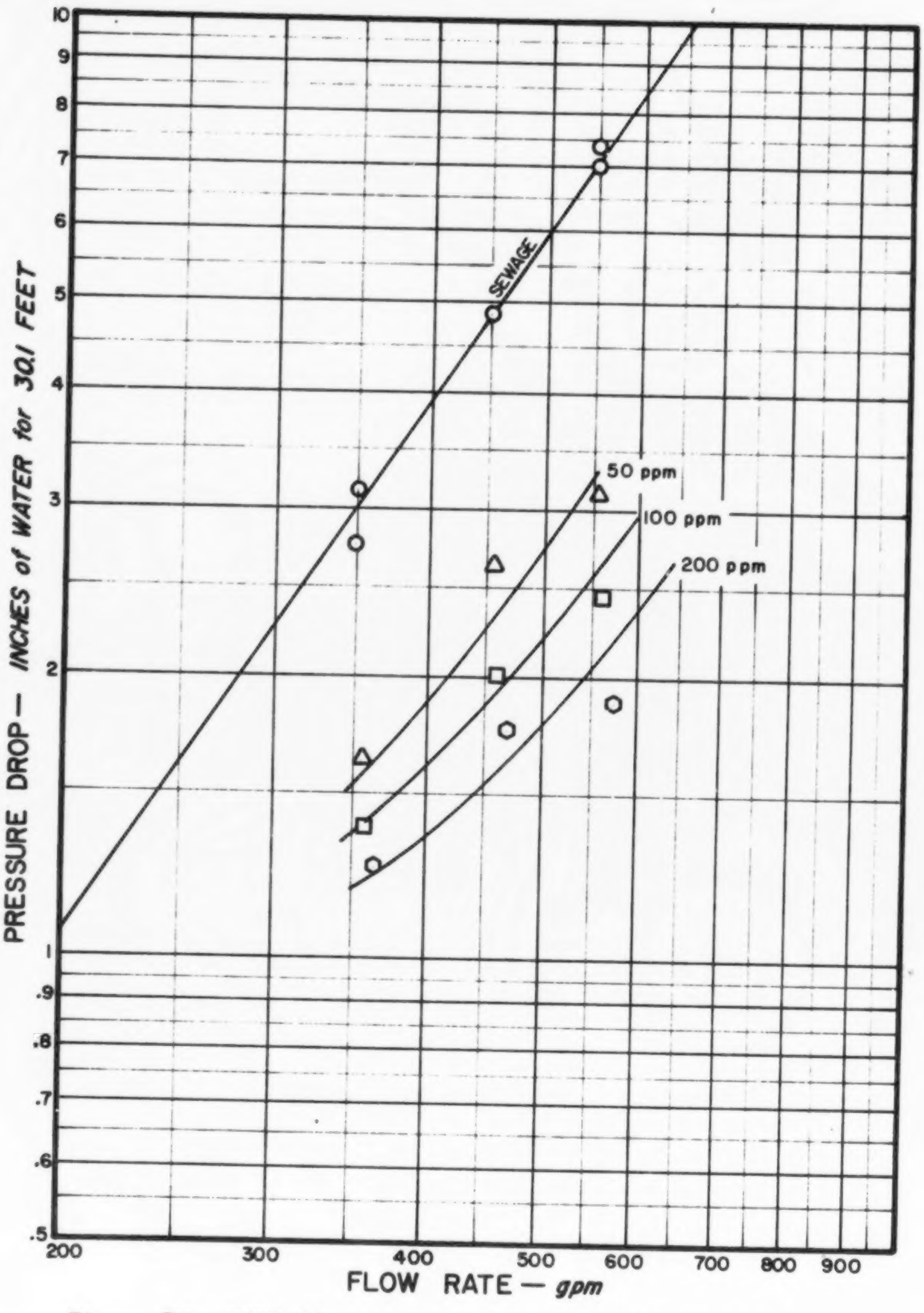

Figure C5. WSR-301 in Six-Inch Test Facility at 70^0F in Sewage (3 mg/l Settleable Solids).

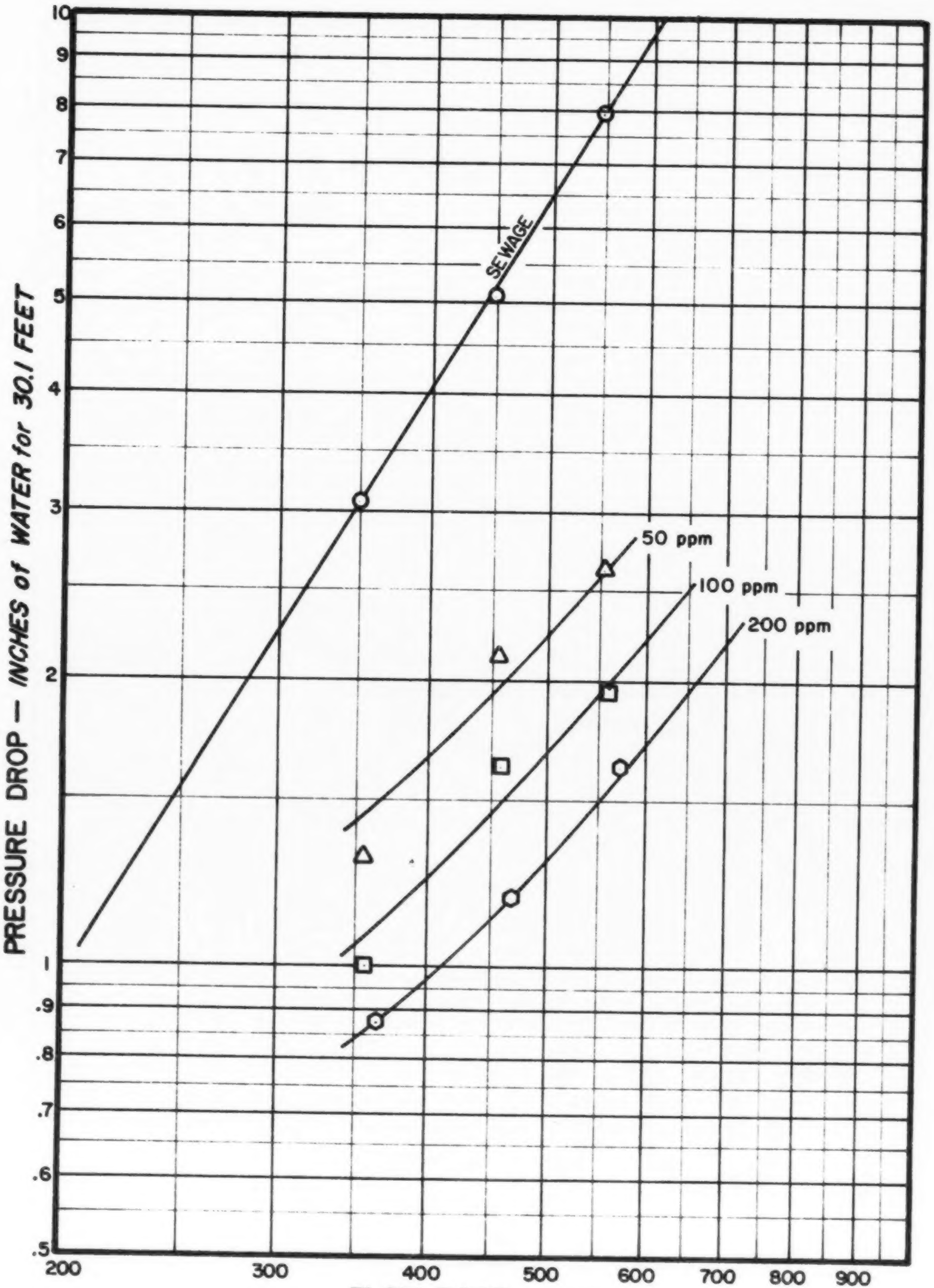

Figure C6. WSR-301 in Six-Inch Test Facility at 70^0F
in Sewage (9 mg/l Settleable Solids).

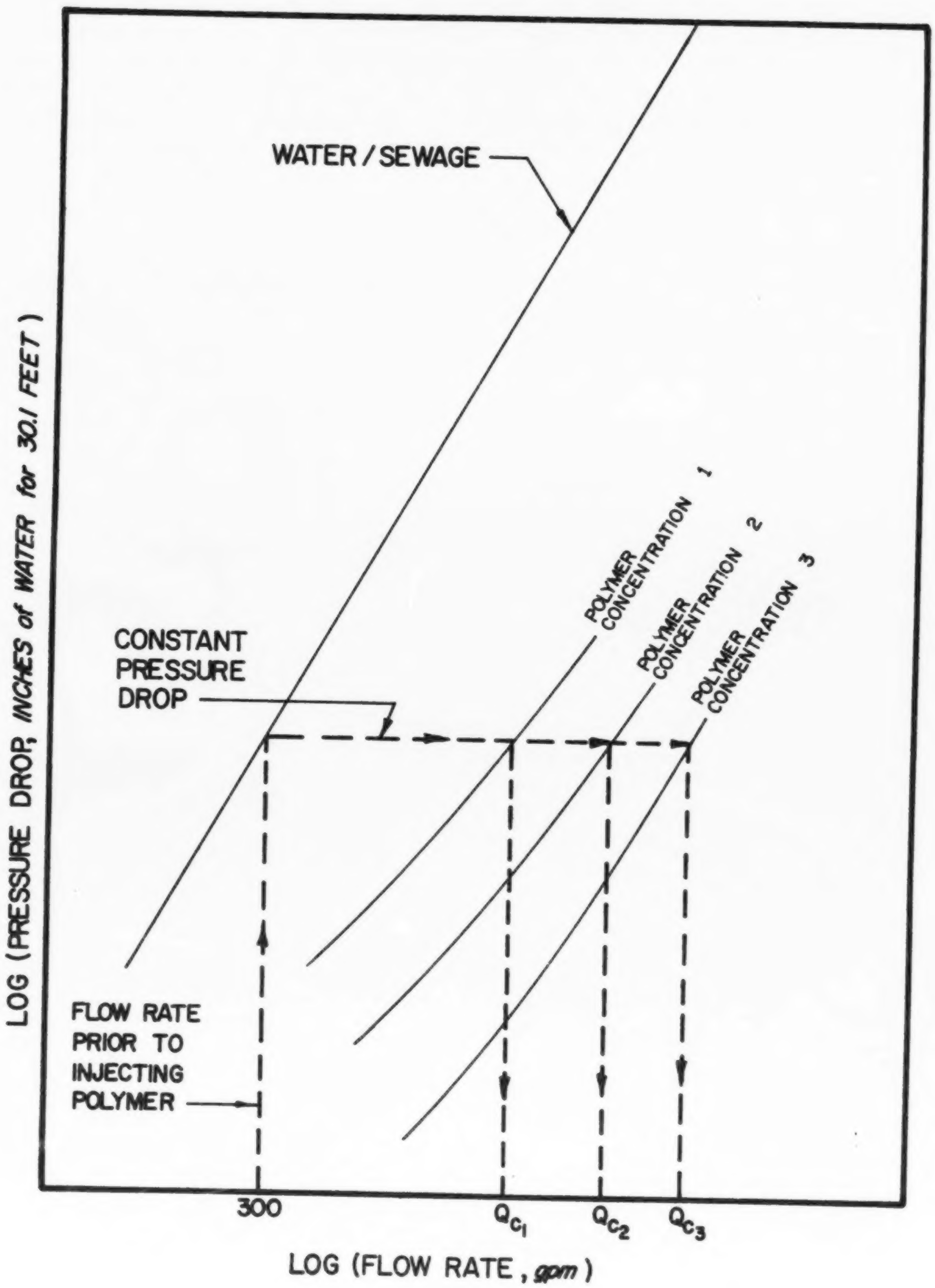

Figure C7. Example of Use of Flow Data to Derive Percent Flow Increase.

the intersection of 300 gpm and the turbulent water or sewage flow line). At this pressure drop or energy level, a horizontal line was projected to each of the curves obtained for the various polymer concentration. At the intersection of this projected line and the curves, vertical lines were projected back to the abscissa to determine the flow rate. The percent flow increase was then calculated by the formula

$$\frac{Qc - 300 \text{ gpm}}{300 \text{ gpm}} \times 100,$$

where Qc is the flow rate in gpm for polymer concentration c. This same procedure and similar calculation was made for a 250 gpm flow rate for each of the selected polymers.

APPENDIX D

POLYMER SLURRY MIXING TECHNIQUES

Rapid dispersion is required to quickly and completely dissolve water-soluble polymer particles in aqueous solutions. The polymer slurry, when fed into an extreme turbulent regime as occurs in the throat of an eductor, was found to be an efficient method of obtaining polymer dispersion without conducting an extensive investigation into numerous mechanical systems. It was found that the majority of polymers used during the six-inch model sewer line testing program could not be rapidly dispersed in aqueous solutions when the polymer was added in a dry state. Massive agglomerations occurred and lengthy hydration times were required when this technique was used.

It was determined, however, that if polymers were suspended in a slurry and introduced into an aqueous solution by the high turbulence of an eductor, the hydration time was greatly reduced. In sewer lines where flow turbulence was present, the total hydration time or solvation process, using the eductor, was reduced to a few minutes.

The process of preparing the slurry involved three major steps: 1) the nonsolvent (isopropyl alcohol) and the gelling agent (klucel H) were mixed thoroughly; 2) the nonsolvent and the gelling agent were allowed to gel; and 3) the water-soluble polymer was added to the gel to complete the slurry. It was important that two precautions be taken during the slurry making process: 1) the gelling agent had to be added carefully to the nonsolvent so that lumps would not form (lumping or agglomeration of the gelling agent in the nonsolvent resulted in much longer gelling times, so a standard number 5 mesh sieve was used to eliminate lumps); and 2) the polymer powder had to be added slowly to insure a more homogeneous slurry.

Initially, only very small volumes of slurry were needed for the six-inch model testing phase of the program. These small volumes did not incur mixing problems, and it was assumed that the same mechanical mixing technique could be applied to larger slurry productions. The principle of using a positive-displacement gear pump as a slurry blending-mixing device was initially used on the 24-inch sewer line tests. The nonsolvent was pumped into the portable slurry tank and the klucel H added. Recirculation and blending were accomplished by using a two-inch positive-displacement gear pump driven by a variable-speed electric motor. The polymer was added to the gel by throttling the recirculation flow while maintaining a constant pump speed, creating a slight vacuum on the suction side of the pump. This vacuum was used to carry the polymers into the gel. The gelled slurry was withdrawn from the bottom of the tank and recirculated back into the top of the tank, which was open to the atmosphere.

This technique proved successful only for slurry volumes of less than 300 gallons. Between 300 and 500 gallons, it became increasingly difficult to achieve a good homogeneous slurry. Above 500-gallon slurry quantities, additional mixing devices were required to obtain a gel. The polymer powder that did not disperse into the gel before reaching the tank tended to adhere to other moistened polymer already in the tank, forming a massive lump of moistened polymer. As a result, the gel would flow around this mass and not mix with the polymer. To avoid this, the slurry tank was equipped with a two-horsepower mixer to provide thorough mixing of the polymer and gel. By using this additional mixing device, 500-gallon batches were gelled in about 12 hours.

Due to the problems encountered, a modified mixing technique was investigated which proved to be effective. The nonsolvent was gelled in two 400-gallon tanks equipped with 1/3-horsepower mixers operated continuously as the gelling agent was added to the nonsolvent. This procedure reduced the total gelling time and provided a better quality gel. After six to eight hours, a homogeneous gel was obtained and transferred into the portable slurry tank unit of the injector. Polymer was then slowly added to the gel, using the method described previously, but maintaining constant agitation of the gel as the polymer was added.

The most efficient method of using polymers in a fluid would be by adding the polymers in a dry state; however, additional work and research will be necessary to perfect and adapt such a method for use in making large slurry batches.